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U.S. DEPARTMENT
OF COMMERCE,
WASHINGTON

**Interstate Highway 95, north of Fredricksburg, Va.**

Design of this recently completed part of I–95 retained the natural scenic beauty and alined roadways so that median growth and terrain screen opposing headlight glare.

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# Public Road

## A JOURNAL OF HIGHWAY RESEARC

*Vol. 33, No. 7* *April 19*

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# Headlight Glare and Median Width—
# Three Exploratory Studies

*BY THE OFFICE OF*
*RESEARCH AND DEVELOPMENT*
*BUREAU OF PUBLIC ROADS*

**Reported by[1] LAWRENCE D. POWERS,**
**Highway Research Engineer, and**
**DAVID SOLOMON, Principal**
**Research Engineer,**
**Traffic Systems Division [2]**

*The effects that glare from headlights of an opposing vehicle in relation to lateral separations (median width) have on meeting drivers are discussed in this article. Different methods of approach to the problems related to headlight glare and its effect in relation to median width were used in each of three studies. The test methods for each succeeding study were designed to compensate for the limitations of the preceding study and/or studies.*

*The conditions of each study were, as follows:*

*In Study 1, both the opposing glare car and target were stationary; the test subject drove toward the target and indicated when he could detect it. In Study 2, both target and test subject were stationary and the glare car moved toward the test subject; locations of the glare car were determined at which the target was just visible to the test subject. In Study 3, a self-luminous target was used and both target and test subject were stationary as the glare car moved toward the subject; he continuously adjusted the brightness of the target and attempted to keep it barely detectable. Some limited measurements of discomfort caused by glare were made in Study 1, but this line of investigation was abandoned because of the variability in the results and the lack of an adequate definition of discomfort.*

*As expected, study results showed that the effects of glare decreased with increasing lateral separation of the glare car and the opposing vehicle. At any given lateral separation, the effects of the glare were present even when the glare car was at a considerable distance from the observer (3,000 feet or more); the rate of change of the effect with distance was small for a large part of this distance.*

*The authors have made recommendations on how to conduct such target detection studies in the future in order to obtain the most meaningful results. The entire visual problem of driving at night is discussed and possible areas for future investigation are suggested.*

## *Introduction*

THE METHODOLOGY and the results of three exploratory studies on the relation of the median width of a highway and the disabling effects of opposing headlight glare are published in this article. The three studies, in each of which different test methods were used, were made to gain insight concerning the factors producing headlight glare and the relationship of these factors to median width. Because insight was the main objective of these studies, only small amounts of data were collected and little reliance has been placed on the quantitative results.

The methods used in each succeeding study were developed to compensate for the limitations revealed in the analysis of the preceding one. These studies were all made in the spring of 1961, but the preliminary report was not published because of the recognized limitations in the data developed or because of the difficulty in interpreting the results. Readings in the psychological and physiological literature have provided a basis for an interpretation of the results. Information is presented here for those who may be contemplating research in the same area. Therefore, considerable detail has been included on field layouts, procedures, and qualifications of results. Discussions of possible pitfalls and factors that may have to be considered are also presented.

The results of these studies were based on small samples and few replications. They are more suggestive than conclusive and are of value primarily to show the types of results that may be expected and to illustrate effects of certain factors. The absolute values of the results hold only for the particular targets, subjects, surroundings (pavements, backgrounds, ambient illumination), and lamps tested. The relative values of the results such as the effect of lateral separation may also be dependent on these variables.

It had been proposed that the discomforting as well as the disabling effect of headlight glare be studied. The discomforting effect, however was elusive of definition and more so of measurement. An attempt to measure it was made in Study 1, but the results were too variable to be of any use. Thereafter the objective was limited to what was thought to be the more critical problem of disabling glare.

Data for Studies 1 and 2 were collected in one night each and for Study 3 on two successive nights. The data are not considered to have been biased because of serial changes in conditions. Although different ambient illumination conditions may have existed on the different nights, it is assumed that they were fairly constant for the duration of each night; furthermore, balanced experimental designs and random orders of exposure were employed for the different conditions such as lateral separation. When the data are subject to question for other reasons, qualifications for the results are given. The existence of possible differences between nights, as well as differences in some of the other variables, reduces the comparability of the results of the different studies.

## *Notes and Definitions*

The test site, 2 miles long by 150 feet wide, was a new portland cement concrete runway at Dulles International Airport, prior to its being opened to air traffic. The site was 25 miles from downtown Washington and about

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[1] Presented at the 43d annual meeting of the Highway Research Board, Washington, D.C., Jan. 1964.

[2] The authors express their appreciation to W. P. Walker, who suggested these studies; R. M. Michaels, for providing consultation and advice prior to and during the studies; N. Schwab, for reviewing the visual theory contained herein; the Federal Aviation Agency, for permission to use the runways at Dulles International Airport; and to the many people who participated as test drivers or field crew: P. Walker, D. Merchant, R. D. Desrosiers, R. E. Payne, L. Poland, R. Wells, J. P. Eicher, and P. Granum.

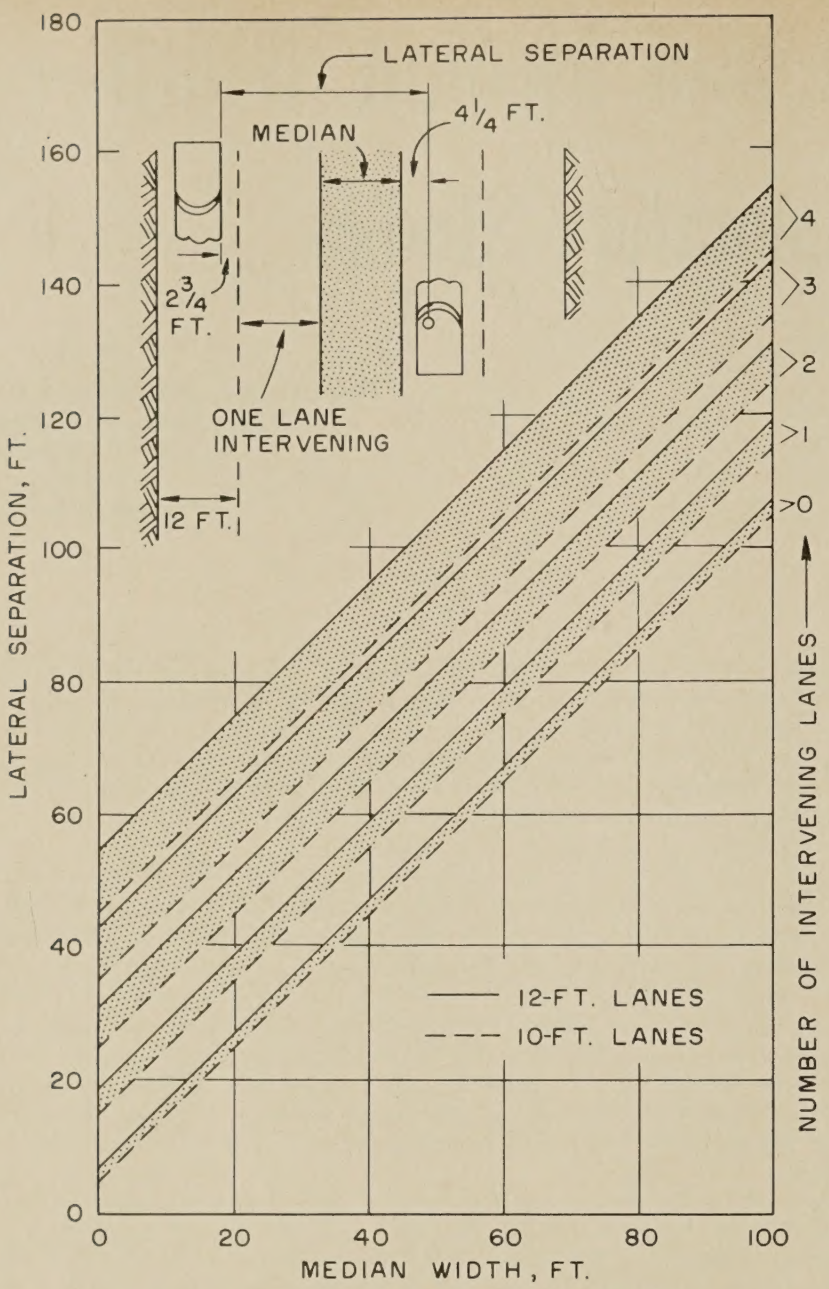

*Figure 1.—Relation between lateral separation and median width for different combinations of vehicle position and lane width.*

12 miles from the nearest sizable town. The area surrounding the runway was flat and grassy. Consequently, the ambient illumination was uniform and at a very low level. Few, if any, extraneous light sources were visible, depending on the direction in which the test subjects were facing for the different studies. When present, these lights were distant and constant during the collection of data. For the conditions of the studies, the effects of cross-slope of the runway were assumed to be negligible so that, except where noted, all studies were performed on portions of the runway considered to be a plane surface.

The tests simulated only the meeting of a single vehicle and a single opposing *glare* vehicle on a constant-grade, tangent section of highway, where, at any cross section, the pavements for both directions of travel were at the same elevation. The results do not necessarily hold for other geometries.

All vehicles employed in the studies had four headlamps mounted horizontally. Prior to each study, the aim of the headlamps of both the glare car and the car for the test subjects was adjusted according to Virginia State standards. All tests were conducted with the glare car headlights on high beam. The windshield of the car in which the test subjects were seated, the outsides of the headlamps of both the glare car and test subject's car, and the reflectors on the target car were maintained clean throughout the course of the studies.

**Lateral separation**

Instead of median width, the more definitive concept of *lateral separation* is used in this report. As employed here, *lateral separation* refers to the lateral distance between the test subject and the near side of the opposing glare vehicle. Lateral separation can be used to convert (figure 1) to different combinations of median width, vehicle position, and lane width. For the conversion it has been assumed that each of the two vehicles is 6.5 feet wide and centered in its lane; the test subject's eyes are assumed to be 1.5 feet from the left side of his vehicle. Following is an example of how figure 1 may be used, when conditions are: median width, 20 feet; four-lane divided highway; both vehicles in their respective right lane (two lanes intervening); lanes, 12 feet wide; then the resultant lateral separation is 51 feet.

The condition in which no opposing vehicle was present can be thought of as corresponding to an infinite lateral separation. For convenience, this condition (absence of opposing vehicle) is referred to as the *no-glare* condition although, technically, any light in the field of view will produce some glare, such as the area of pavement illuminated by the driver's own headlights.

**Longitudinal separation**

Although the tests were run at slow speeds and for long distances—2,000 feet or more—these distances were not so extreme as they may appear at first glance and actually were not long enough to develop all the needed data. On modern, divided highways, sight distances of several thousand feet to opposing headlights are fairly common. Two opposing vehicles, each traveling at 70 m.p.h., will have a relative velocity of about 200 feet per second. If the two vehicles are initially 2,000 feet apart, they will meet in 10 seconds.

**Threshold**

Psychophysical *absolute threshold*, according to Stevens (*1*),[3] is the level of a stimulus—one example is the brightness of an object—that marks the transition between response (detectable) and no response (nondetectable). This threshold level ordinarily fluctuates from moment to moment within a range separating those stimuli levels that definitely produce a response from those that definitely do not produce a response. A given stimulus will produce a response only part of the time. The probability of detection of a stimulus, therefore, will range from close to zero to almost 100 percent. Usually, the stimulus level that produces a response 50 percent of the time is called threshold (50 percent threshold). For identical conditions, the average thresholds for different subjects may be different. The term *threshold* has been used throughout this article, but it is used in a much less restrictive manner and refers, generally, to when the test subject reported that he detected or lost sight of the target. Obviously, the conditions of exposure of the stimulus—time of exposure of the target, subject's adaptation levels, and criterion for confidence of detection—could not be controlled so precisely as in a less realistic laboratory setup, and the individual threshold measurements reported herein could have differed considerably from the 50-percent detection level.

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[3] References indicated by italic numbers in parentheses are listed on p. 141.

## STUDY 1

The field layout [4] for Study 1 is shown in igure 2. The headlights of both the glare car nd the test subjects' car were on high beam. The glare car and the target car were both tationary, the rear of the target car being 00 feet beyond the headlights of the glare car. Of the five test subjects, three in their 20's and ne 54 years of age reported normal or corrected-to-normal visual acuity; one, age 33, eported poor acuity.

Each test subject, using a pavement joint s a guide, drove toward the rear of the unghted target car at a speed of 20 miles per our. His instructions were to call out to a ecorder seated in the car when he felt the lare to be discomforting and again when he ould discern any part of the target car (the art of the target car first detected in every un was one or more of the six, rear red eflectors). Distance markers, 40 feet apart, ned the edge of the runway. The recorder ould note the position of the car relative to he nearest distance marker; from this information the longitudinal distance could be stimated to within 20 feet. The course narkers carried reflectorized letters that were urned away from the view of the test driver. The recorder viewed them by shining a ashlight out the side of the car.

Each test subject made three runs at each of our different lateral separations of 7, 32, 57, nd 82 feet, and also for the no-glare situation, hich corresponded to an infinite separation. uns were made in random order, although ach subject made all his runs consecutively. or each different lateral separation the arget car was positioned so that it was irectly ahead of the test subject's car.

The method used in Study 1 is similar to hat used by the Idaho Department of ighways in a 1957 glare test (*2*).

The glare car was not moved at all during tudy 1, as all data were collected in one ght. Therefore, the orientation of the eadlight candlepower distribution was constant for all runs. However, it is not known hether the axis of the glare car, and consequently of the headlights, was exactly parallel the line of travel of the test subject.

### *Discomfort Results*

Study 1 is the only study of the three for hich data relative to both disability and scomfort glare were obtained. The results the discomfort test showed that the discomfort measurements were highly subjective d variable.

For the different lateral separations, data i figure 3 show the distances from the glare hicle at which subjects stated they experienced discomfort from the opposing headlights. The grid portion of the figure can be viewed as a plan of the test site. Each subject is identified by a different letter, A through E. The points are plotted at the distances for each run at which the test subject reported discomfort; when the subject reported no discomfort during a run, a point is shown to the left of the zero line. For two runs at each of the two narrowest separations, subject E reported discomfort at the beginning of the run before he arrived alongside the beginning of the series of distance markers (2,520 feet). Therefore, these distances are unknown, but were more than 2,520 feet and have been plotted arbitrarily at 2,700 feet.

A curve has been drawn for each subject. These curves are approximate because of the extreme scatter of the data. Had each curve been drawn to pass through the mean discomfort distance for each lateral separation, some of them would have been S-shaped. As had been expected, the distances at which the onset of discomfort was reported generally increased as lateral separation was decreased; or, to put it simply, discomfort was experienced sooner when the lateral separation was narrow. When 1,000 feet from the glare source, for example, subject A stated that he experienced discomfort only when the lateral separation was 7 feet. Discomfort was reported by the others, as follows: subject B, when the separation was 32 feet or less; subject C, when the separation was 57 feet or less; and subjects D and E, even when the lateral separation was 82 feet.

For any given run, as the distance between the subject and the glare car decreased and the opposing headlights became farther from his line of sight and decreased in brightness, obviously points had to be reached at which discomfort began to diminish and at which it ended, even if one or both of these points were where the driver passed the glare car and the headlights were no longer visible. Therefore, the discomfort threshold curves must bend over at small longitudinal distances. Data were not collected for these points on the discomfort curves, but for illustrative purposes they are shown as the broken-line parts of the curves for subjects A, B, and C.

Part of the differences in results may have been the result of the subject having had two tasks to perform: to report discomfort and to report detection of the target. As detection of the target was the more emphasized task, subjects may have failed to concentrate or report on discomfort if it occurred at the same time that the target became detectable. But the differences in results among subjects undoubtedly were caused both by differences in sensitivity to glare and individual definitions of discomfort. However, it was hard to believe that the large scatter for any individual could be attributed to the small sample size alone, and it became apparent that discomfort glare criteria were going to be difficult to define. Subsequent research was therefore limited to the study of only disability glare.

### *Target Detection*

Data in figure 4 show how target detection distances change with lateral separation. The part of the target car detected first was always one or more of the six, rear red reflectors. Each plotted point represents one run by one subject at the lateral separation indicated. The data for each subject are shown by a different symbol. The data seemed to fall into two distinct groups, apparently according to the nighttime visual ability of the subjects. Consequently, they have been so grouped. The solid curve is for the three subjects in their 20's, who had reported normal acuity. The lower dashed curve is for the other subjects: the one 33 years of age who had reported poor acuity and the one 54 years of age who had reported normal acuity. For purposes of identification, the group of three, who were judged to have normal visual ability, have been given the designation N; the other two subjects, whose performance was judged to be somewhat lower, have been designated L. Within each group the differences between subjects appear small and curves drawn for individual subjects would approximate the curve for that particular group. The alternate dashed and dotted curve shows an average for all five subjects (fig. 4).

As had been expected, the distances at which the target was detected increased as lateral separation increased. Average detection distances appeared to approach those of the no-glare condition at lateral separations of approximately 80 feet. However, the curves for the two sets of subjects are somewhat different in that the curve for the two subjects (L) approaches a maximum at a slightly narrower lateral separation compared to the curve for the three subjects (N). The apparent anomaly for the two subjects (L) of greater detection distance at the 80-foot lateral separation than for the no-glare situation can be attributed to the small sample size. Otherwise a new theory would be called for. Data from the Idaho study, in which a different target was employed, have also been plotted. The median widths given in the Idaho report have been adjusted to the same lateral separation assumption used for Study 1. Data for wider separations or for no-glare situations were not included in the Idaho study, so the shapes of the curves for the different targets cannot be compared.

### *Visibility and Discomfort Compared*

The performances of the subjects in the visibility test of Study 1 were compared with the discomfort test to see whether there was any correlation between the two measurements. The two subjects (L), who showed somewhat poorer visual performance, are shown as B and E in figure 3 for the discomfort test. Subject E, age 54, reported discomfort at all lateral separations; whereas B, age 33, who had reported poor acuity, reported discomfort for only the two narrowest separations. The discomfort results for the other three subjects, A, C, and D, were divergent,

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[4] As employed in this article, *layout* refers to the plan of the s for each study; *setup* refers to the relative position of glare c and target car.

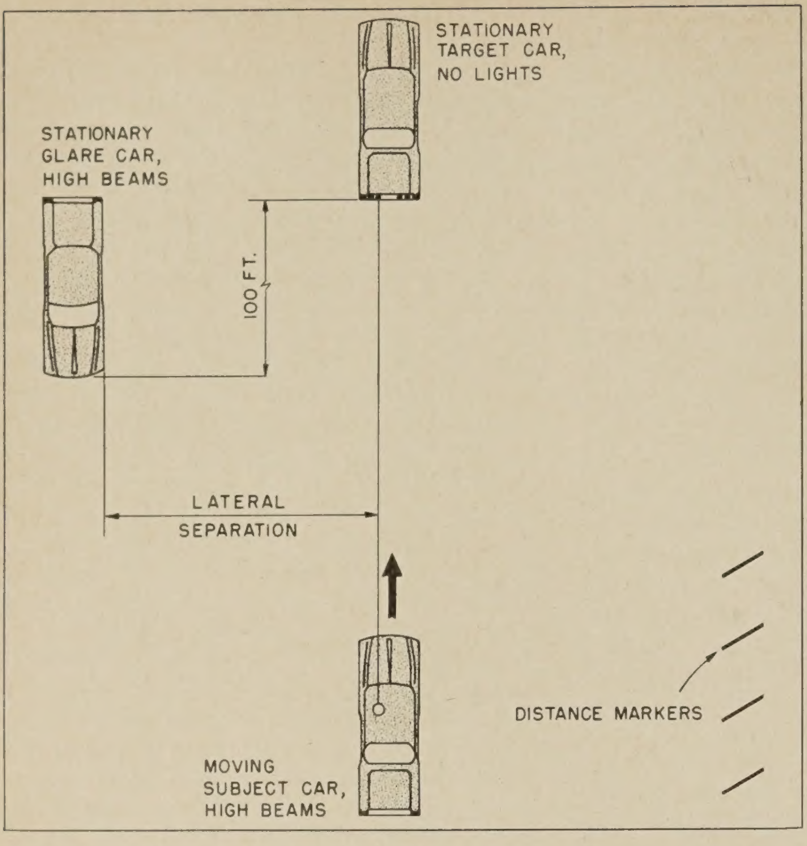
STATIONARY TARGET CAR, NO LIGHTS
STATIONARY GLARE CAR, HIGH BEAMS
100 FT.
LATERAL SEPARATION
DISTANCE MARKERS
MOVING SUBJECT CAR, HIGH BEAMS

*Figure 2.—Field layout for Study 1.*

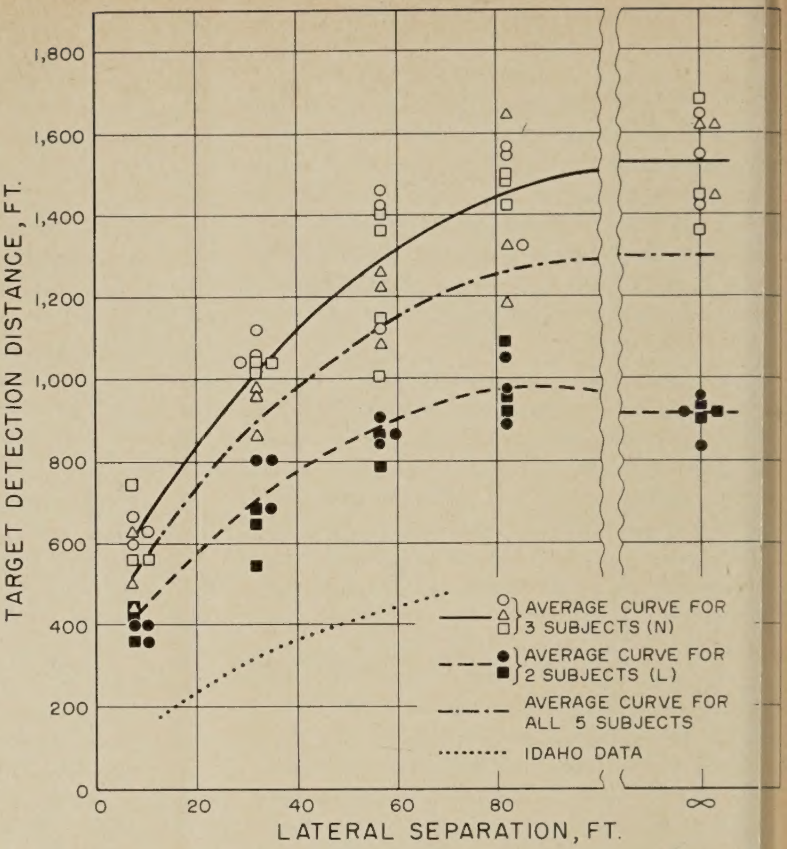

*Figure 4.—Target detection distance by lateral separation for ive subjects in Study 1, target 100 feet beyond glare car. (Ic ho data are for a different target.)*

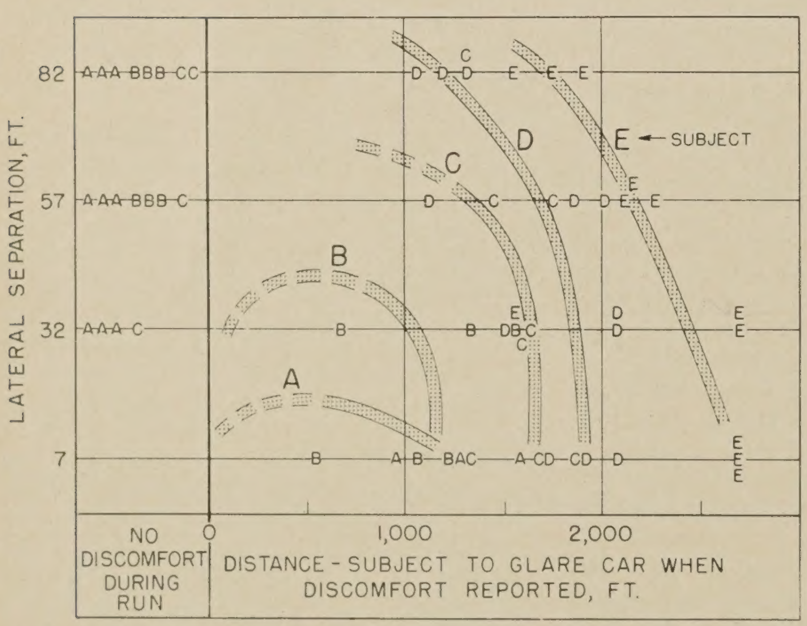

*Figure 3.—Effect of position of opposing high beams on discomfort reported by five subjects. Each lettered point is plotted at distance at which subject reported onset of discomfort for each run at given lateral separation. Presence of discomfort was assumed for combinations of lateral and longitudinal separation from glare car that lie under the curve.*

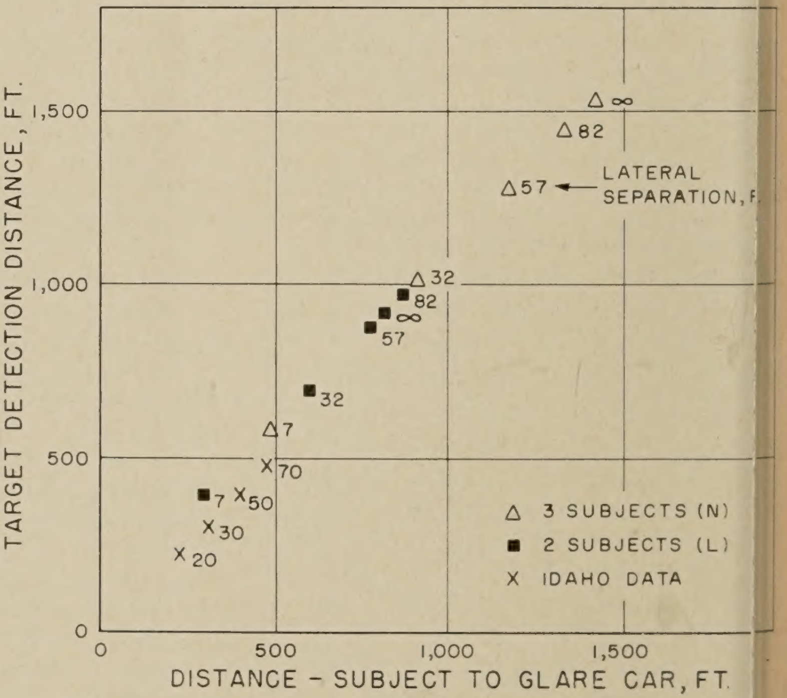

*Figure 5.—Relation between target detection distance and is-tance of glare car for different lateral separations for the me od of Study 1. (All data fall on a line, which has a slope of u ity and an intercept of 100 feet.)*

whereas their performances in the visibility test were nearly identical. On the basis of these limited data, therefore, there is no evidence of a correlation between visual sensitivity and discomfort sensitivity to glare.

## *Limitations of Study Procedure*

The differences in the target detection distance curves for the two groups of subjects may be related to the fact that automobile headlamps send out focused beams ith different light intensities at different a gles from the axis of the lamp. This may ex ain why the curve for the two subjects (L) approaches the no-glare value at smaller la ral

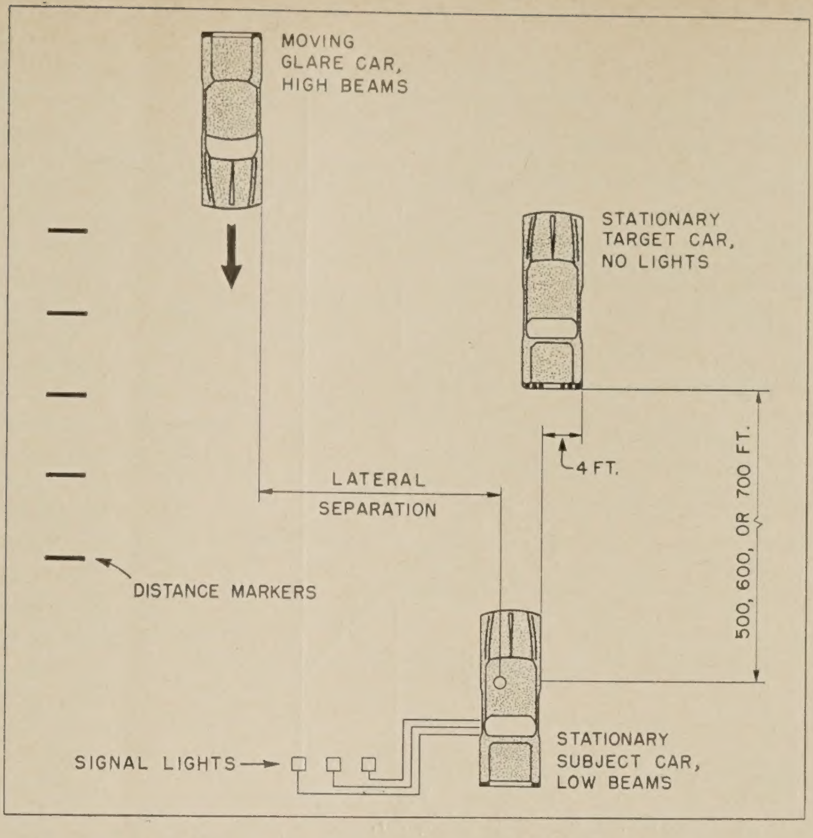

*Figure 6.—Field layout for Study 2.*

eparations than does the curve for the three ubjects (N). Because of poorer visual abilty, even without glare, the former group had o be closer to the target to detect it under ny condition. Being closer to the target, hey were also closer to the glare car but were ubjected to lower intensities of opposing lare. The three subjects (N) were able to etect the target at longer distances for the o-glare situation. At these longer distances nd the same lateral separation, they were ubjected to higher levels of glare and the xtent of the reduction in target detection istance was greater. This same interaction etween level of glare and detection distance ay also produce different relationships beween lateral separation and detection distance or different targets because the observer will e in a different orientation to the opposing eam for each target at the time it becomes etectable.

Reevaluation of the study procedures for tudy 1 showed conditions that limited the pplicability of the results obtained for disaility glare. Among these were the dependnce of the results upon the particular geomtry, headlight configurations, test subjects, nd target used in this experiment. A major mitation of the data, however, was that the elative positions of target and glare car were xed, as shown in figure 2. As the subject pproached both the glare car and the target, is position with respect to the opposing headght beam pattern changed simultaneously ith the change in apparent size of the target nd the illumination on it from his own headghts. Regardless of when the subject could detect the target, the detection distance was always equal to the glare car distance plus 100 feet. This is further illustrated in figure 5, in which a comparison is made of detection distances with distance to the glare car. All the data of Study 1 fall on a line; the equation is:

$$D_t = D_g + 100 \qquad (1)$$

Where,

$D_t$=target detection distance,
$D_g$=distance, driver to glare car.

Similarly, the Idaho data fall on a line:

$$D_t = D_g \qquad (2)$$

because the target was adjacent to the glare car. When this study methodology is used, detection distances of the target cannot be determined for other relative positions of glare car and target car. For example, if the subject were 1,000 feet from the glare car and the lateral separation was 7 feet, at what distance would he have been able to see the target. In attempting to describe the relationship between the effects of headlight glare and lateral separation, it is necessary to know whether the detection distances derived were the most critical distances. The question remains, in regard to the results of Study 1, were these the minimum detection distances for each lateral separation?

The lack of applicability of the data that was caused by the study method was the result of the lack of independence of the two variables: distance to target and distance to glare car. Therefore, this study method was abandoned in favor of one in which only one distance at a time was changed.

## STUDY 2

Essentially, the objective of Study 2 was to determine the positions of the glare car for each of the specified target detection distances. The field layout for Study 2 is shown in figure 6. In this study the subject and target cars were stationary and the glare car, which had high beams on, was moving. The subject car's headlights were on low beam. This is considered to be the worst condition for a two-car meeting situation.

The three test subjects reported visual acuities ranging from poor to good. Each subject was provided a pushbutton that he could use to operate a signal light, a different color for each subject. The signal lights, consisting of 1-foot squares of red, yellow, or green translucent plexiglass illuminated from behind by incandescent bulbs, were situated out of the view of the subjects and sufficiently far apart to be distinguishable at distances up to 3,000 feet by the experimenters.

The three subjects, seated in the subject car (two in front, one in rear), viewed the rear of the target car as the glare car moved toward them. As long as the reflectors of the target car were visible to him, each subject kept his particular signal light on. Subjects were instructed not to communicate with each other during a run.

The same distance markers that had been used in Study 1 were placed at intervals of 100 feet along the side of the test site so they were facing the glare car. The glare car contained three men: a driver, an observer, and a recorder. The driver's func-

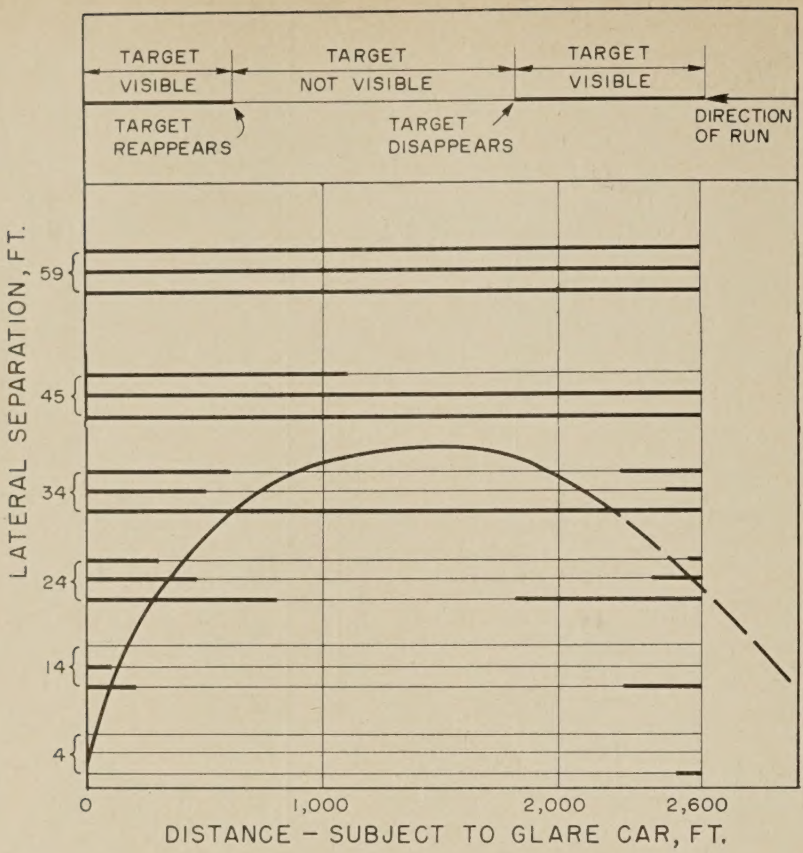

*Figure 7.—Target visibility data and threshold curve for one subject, Study 2. (The target, 700 feet from the subject, was not visible when glare car was at combinations of lateral and longitudinal separations below curve.)*

tion was to stay on course, maintain a speed of 25 m.p.h., and call off the distance markers as they were passed. The observer would call out the status of the signal lights, on or off, and the recorder would enter this on the data sheet for the appropriate marker designation. Distances were estimated to the nearest 50 feet. The farthest marker was at a distance of 2,600 feet from the subject.

Three runs were made at each of six different lateral separations (4, 14, 24, 34, 45, and 59 feet) and for each of three different distances of the target car: 500, 600, and 700 feet. The irregular figures were used for lateral separations because of the convenience of using the pavement joints as tracking guides. Separations of 4 and 14 feet were intended to bracket the zero median test situation, which for lanes 12 feet wide would provide a lateral separation of 7 feet. The target car was offset 4 feet laterally to the right of the subject car, primarily to provide clearance for and prevent displacement by the glare car during runs at the narrowest separation.

The order of presentation of the different target distances was arranged in sets; a set consisted of one each of the three target distances, 500, 600, and 700 feet. For each target distance within a set of three, one run was made at each lateral separation, in random order. The order of target distances within a set was random; three sets were run.

The distance at which each of the three drivers could see the reflectors on the target car without the presence of the glare vehicle was recorded once, respectively.

## *Development of Data*

The following detailed description and discussion of the development of the data from raw to final form will be of value because many factors involved in visibility testing are pointed out.

Figure 7 shows the positions of the glare car at which the target was visible at 700 feet to one of the subjects. Data for three replications for each lateral separation are shown. The figure can be viewed as a plan of the test site. The glare car ran from right to left; the measurements started at a longitudinal distance of 2,600 feet from the test driver. At some point the test subject could no longer see the target: visibility fell below threshold. As the glare car continued its run, a point was reached at which the subject could again see the target. An average threshold curve has been roughed in. Points below the curve represent positions of the glare car—combinations of longitudinal and lateral separation—at which the target was not visible to the subject at a distance of 700 feet; that is, the target detection distance was less than 700 feet.

When lateral separations were narrow, the target was often below threshold for the subject before distance measurements could be taken on the glare car. Consequently, the far end of the threshold curve (fig. 7) has been drawn with a broken line to indicate the extreme uncertainty of its location. The curve has been extrapolated beyond 2,600 feet in order to illustrate the method. Had the glare car measurements been started at a longer distance, there would have been some point at which the target would have been above threshold.

Also for narrow lateral separations, the target did not rise above threshold until after the glare car had passed the subject. This could have been caused by: the timelag in the subject's readapting to the no-glare condition, reaction timelags in actuating the signal buttons, and reaction timelags in the observing-recording process. All of the longitudinal distance data are probably too small because of timelags in the signaling-observing-recording process. To simplify the illustrations, the threshold curves of figures 7 and 8 have been drawn as though the target were always visible after the glare car had passed the subject.

At the wider separations, the target was sometimes above threshold during the entire run of the glare car; that is, the target detection distance was always more than 700 feet. This was true for one of the runs when the separation was 34 feet, for two runs when the separation was 45 feet, and for all three runs when the separation was 59 feet (fig. 7). As threshold is usually defined as a 50-percent probability of detection, the threshold curve has been drawn to level out at the lateral separation where the target was detectable 50 percent of the time, or 1.5 times out of three runs. Therefore, the curve has been drawn to level out in the vicinity of the 1,500-foot longitudinal distance, where a minimum point would appear to be, and midway between the 34- and 45-foot separations where the target was detectable for the entire run, once and twice out of three runs, respectively. Many more replications would be needed to determine the exact location of the average threshold curve. For purposes of illustrating the method, it was assumed for this analysis that 50-percent detection threshold data were being obtained. However, it is doubtful that the points where the target appeared or disappeared represent 50-percent detection thresholds.

Figure 8 shows average threshold curves for the combined data of all three subjects for each of the three target distances. The parts of the curves shown with broken lines are uncertain for the same reasons that the broken lines in figure 7 are uncertain. The curves can be thought of as representing contours of equal disability caused by glare, as the target detection distance was constant for all positions of the glare car that lie along each curve. The target was not visible at the distance shown for each curve for combinations of lateral separation and longitudinal distance of the glare car that lie under the curve. In figure 8 the shapes of the curves drawn are deceptive because of the difference in the horizontal and vertical scales; the curves actually are very long and flat, indicating that the effect of the opposing glare on target detection was fairly constant over a long distance from the glare car.

The target detection distance can be shown in another way. By noting the distances of the glare car at which a horizontal line, representing a chosen value of lateral separation, intersects the threshold curves of figure 8, the relation between target detection distance and distance of the glare car for that particular lateral separation can be obtained. Points of intersection so obtained have been plotted in figure 9 for arbitrarily chosen lateral separations of 7, 17, 27, and 37 feet. At separations wider than 37 feet, the target detection distance was always more than 700 feet and, as target distances of more than 700 feet were not tested, no points could be obtained for these wider separations. Curves showing changes in target detection distances by position of the glare car for the chosen lateral separations have been drawn through the points. Again, the uncertain parts are shown by broken lines. The average no-glare detection distance of 940 feet for the three subjects was derived from only one measurement per subject and, is, therefore, shown by a broken horizontal line in figure 9.

### Study 2 Results and Discussion

The curves (fig. 9) illustrate that target detection distance was relatively high at long distances from the glare car. This is reasonable, as the illumination reaching the subjects' eyes from the opposing headlamps was small. Target detection distance decreased gradually as the glare car got closer to the subject, reached a minimum, and then rose again as the glare car, continuing its run, moved away from the center of the visual field and the less intense part of the opposing headlight beam was directed at the eyes of the subject. As the lateral separation increased, the minimum target detection distance that was reached was higher and appears to have occurred at farther distance from the glare car.

The extent of the curves and the low rate of decline in target detection distance in relation to glare car distance show that the effect of the opposing glare on target detection distance extends for a considerable distance from the opposing glare car and is fairly constant over most of that distance. This was previously pointed out for the threshold curves of figure 8, from which the curves for figure 9 were derived. Also, as previously stated, at lateral separations of more than 37 feet, the average target detection distance was more than 700 feet. Similarly, the curve of target detection for the 7-foot lateral separation dips below 500 feet to an unknown point. Therefore, to have obtained data from which to draw the curves for lateral separations of more than 37 feet and to have obtained the minimum target detection distance for the 7-foot lateral separation, target distances of more than 700 feet and less than 500 feet would have had to be tested. The minimum points for the curves fall at points for target detection distance at which no data were obtained. For a more accurate determination of the minimum target detection distance and its location for each lateral separation, intermediate target distances would have had to be tested.

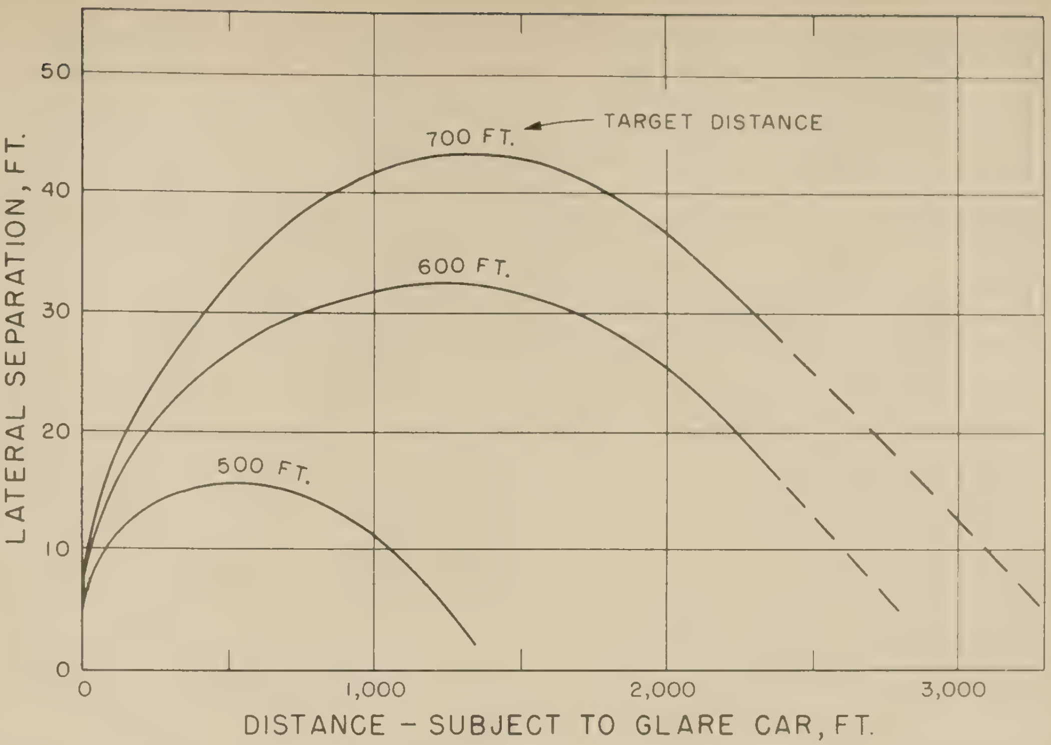

*Figure 8.—Average threshold curves for three subjects of Study 2 for each of three target distances. Target was not visible at distance indicated on each curve when glare car was at combinations of lateral and longitudinal separations below curve.*

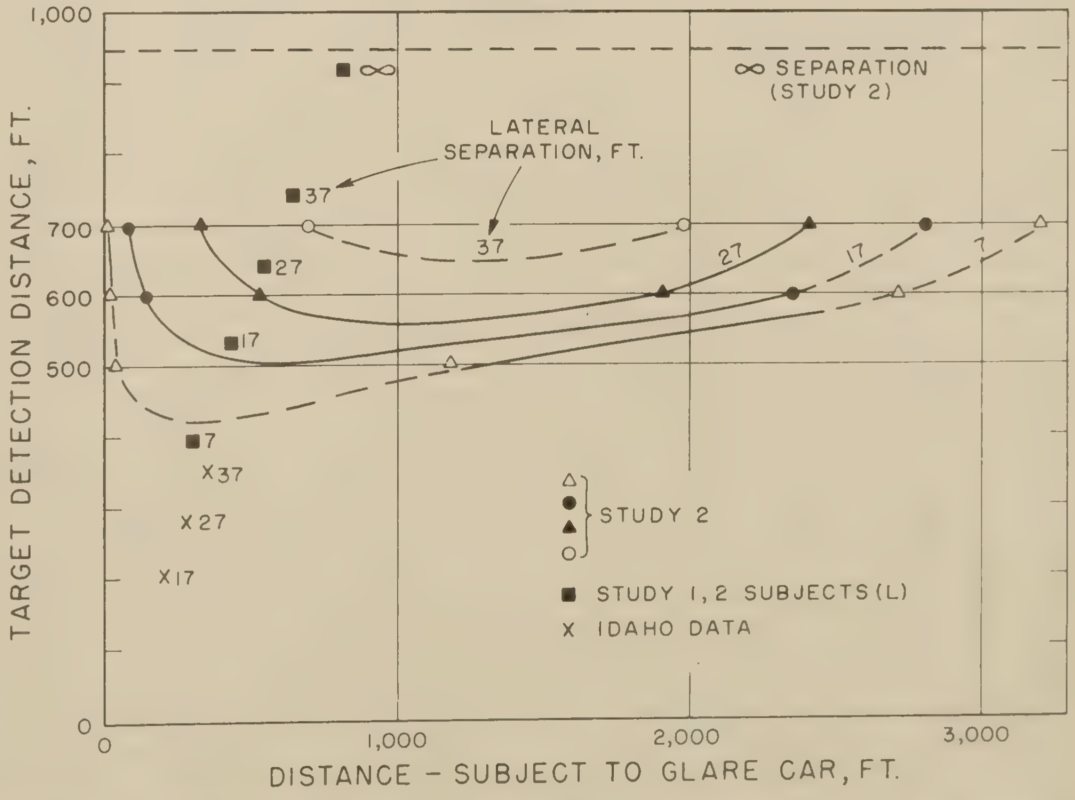

*Figure 9.—Target detection distance in Study 2 by glare car distance for different lateral separations. (Partial data of Study 1 and Idaho study shown for comparison.)*

The slope of the curves for glare car distances beyond 2,000 feet is uncertain because these parts of the curves were based on extrapolations of the threshold curves. Another cause for suspicion about the shape of the curves in this area is inherent in the study method. Because the target was at a fixed distance from the subject, the threshold point of detection for long distances of the glare car was determined when the target, initially visible, became invisible. The subject was therefore able to fixate on the target and could maintain detection of it for a longer time, as the glare car approached, than if the target had been initially invisible and then became visible. It is possible that target detection distances for the long distances of the glare car should be less than shown. The shapes of the curves obtained in similar studies by the Road Research Laboratory in England (*3*, *4*, *5*) do not have as great a slope as the curves of figure 9 at the long distances of the glare car.[5]

The roundabout method of developing the data just demonstrated, which involved drawing the threshold curves (fig. 8) and intersecting them with chosen lines of lateral separation in order to obtain points with which to plot the target detection distance curves (fig. 9), was used to illustrate some important concepts such as the variability in threshold measurements.

The average distance of the glare car for threshold detection of the target could have been plotted for each target and lateral separation directly on figure 9. It would not have been possible, however, to have interpolated for lateral separations other than those at which data were actually obtained.

### Disadvantages

Although the method described in the preceding paragraph is direct, the problem remains of what to do where some, but not all, runs at a particular lateral separation do not provide threshold points because the target was detectable for the entire run. This points up a fundamental disadvantage of the method used in Study 2. Because the use of this method yields distances from the glare car at which target detection distance is constant, the data essentially fall on lines of constant target detection distance, as in figure 9. The curves of target detection distance by glare car distance that are derived from these data are long, flat curves, indicating the glare levels (disability contours) that cause particular threshold detection distances, which are long in extent and roughly parallel to the line of travel. If these disability glare levels can be visualized as long and thin, cigar-shaped contours emanating from the glare car, it can be seen that their intersection with the subject's line of travel is at a very small angle. This small angle of intersection combined with the variability inherent in threshold measurements produces such a high degree of uncertainty in the location of the actual threshold points that the number of repetitions required for accuracy become impracticable.

### Study Methods Compared

In order to compare the attributes of the two study methods discussed so far, the data of the two subjects (L) who showed poor performance in Study 1 are shown on figure 9. Although these data of Study 1 closely approximate those of Study 2, the data of the two studies are not exactly comparable because of the differences in subjects, beam configurations, and methods of testing. Therefore, the fairly close apparent agreement may be mere coincidence. The data for the other three drivers (N) who took part in Study 1 were omitted from figure 9 to conserve space. For the same lateral separations, these subjects were able to detect the target at significantly longer distances; this illustrates the wide differences that may exist between different groups of drivers.

Because a fixed relationship between the glare car and the target was used in Study 1, all the data fell on a straight line (fig. 5). In figure 9, this line from figure 5 intersects each lateral separation curve at only one point, and these points are not necessarily the minimum detection distances for each lateral separation. This illustrates the disadvantages of using only one fixed relationship between glare car and target.

The retroreflectors used as the target in these studies provided a relatively high contrast task. These reflectors have a reflection factor in the order of 1,000, whereas all objects that reflect diffusely have reflection factors smaller than unity. The data of the Idaho study, for a target with a reflection factor smaller than unity, are also shown in figure 9 to illustrate the differences in the magnitude of the detection distance that will be obtained by the use of different targets. Because different targets will be detected at different distances under any condition, they will be detected at different distances from the glare car when it is present. The subject will be exposed to different levels of glare at the point of detection because he will be oriented differently to the opposing headlight beam pattern. Therefore, the curves for other targets might have different shapes than those that were derived from Study 2.

## STUDIES 1 AND 2 SUMMARIZED

Because target detection distance was used as the measure of visibility in Studies 1 and 2 and not in 3, the results of the first two studies are summarized here. Also, methods for conducting detection distance studies are evaluated, a recommended method is described, and the use of detection distance as parameter of visibility is discussed.

One surprising result of the first two studi was the extent, in terms of distances betwe the subject and the opposing vehicle, to whi the opposing glare had an effect and the rel- tive constancy of the effect over a long ran of these distances. Just how far a substant glare effect extends is not known, but t results of Study 2 indicate that visibility w be affected to a considerable extent by oppo- ing headlights at distances in excess of 3,0 feet.

That human beings differ in visual abili and sensitivity to glare was known, but t effect these differences might have on t relation between target detection distanc and lateral separation were highlighted the studies. These differences are show (fig. 4) by comparison of the curves for t three subjects (N) and the two subjects (L It was surmised that the reason for this diff- ence in the relative effect of glare is that t two groups of subjects (differing in init visual ability) were at different distanc from the glare car when the target was threshold for them individually and they we therefore, subjected to different levels of gla when detection was made. If targets different, initial (no-glare) difficulty had be used, the result would have been furth differences in the relation between detecti distance and lateral separation.

### Analysis of Methods

Assuming that target detection distance the criterion chosen for evaluating the effe of glare, recommendations can be made as the study method on the basis of the fi two studies in which target detection dista was the parameter. Figure 10 illustrates several theoretical relationships between t- get detection distance and distance of glare car for three different methods of stu The broken-line curves represent hypotheti typically shaped curves of target detect distance by glare car distance for const lateral separations. The two curves in e graph represent data for different late separations for different targets or for t subjects having different sensitivities to gla The light, solid lines are intended to illustr the manner in which the data would derived for the particular study method un consideration.

The top part of figure 10 illustrates relation of target detection distance to dista of glare car and the manner in which the d were derived for Study 1, in which the opp- ing glare car and the target were station and the subject drove toward the targ The result of this fixed relation between gl car and target was a fixed relation betw distance of the glare car and target detect distance. As shown in figure 5, the data the different lateral separations all fell o diagonal line of unit slope that intersected ordinate axis at a distance equal to the lo- tudinal separation between the glare car the target. This demonstrated that, for

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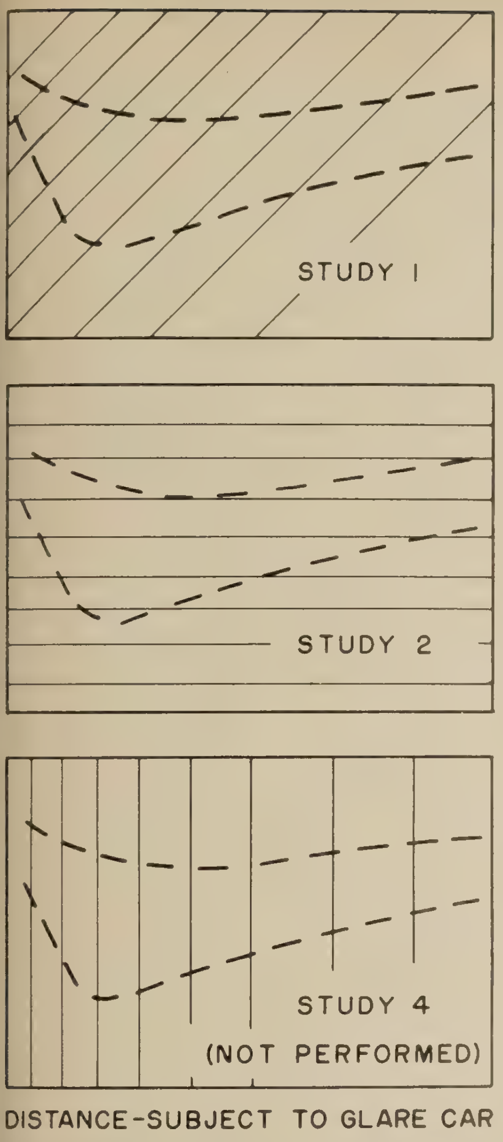
[5] The British studies utilized theoretical expansions of field data. In part, they showed, for British high and low beams and for appropriately aimed American low beams, curves for seeing distance—for straight-ahead and curb-side test objects—that fell gradually with decreasing distance of the glare car and then rose slightly at small distances. It is significant that the curve shapes and the minimum seeing distances varied with different positions of the object across the roadway and with different headlight beam configurations (high beam facing high beam or low beam facing low beam).



*igure 10.—Theoretical relations between target detection distance and glare car distance for different study methods. Curves are hypothetical and light solid lines show generation of data.*

ne setup, a direct relation existed between he distance of the glare car and the distance t which the target was detected. Therefore, he general value of Study 1 was severely mited because all data fell along one of the iagonal lines in the top of figure 10. Howver, this limitation could be overcome by ollecting data for several setups, each of hich would involve a different distance etween glare car and target. The data for ach setup then would fall on one of the iagonal lines in the top graph of figure 10 and curve could be drawn through the approriate points for each lateral separation.

In Study 2, subject and target were both tationary, and the glare car moved. With his method, distances of the glare car were etermined for constant target detection istances. The data, therefore, fell along nes of constant target detection distance, as hown by the horizontal lines in the middle raph of figure 10. The threshold points that ere obtained from the intersection of the ubject's line of travel with the threshold urves (fig. 8) were used to generate the urves of target detection distances by glare car distance (fig. 9). Because the threshold curves extend for such long distances and are nearly parallel to the line of travel, the locations of these points of intersection are subject to large errors. The fact that these curves are nearly parallel to the line of travel indicates that the glare effect was apparently fairly constant for most of the longitudinal distance between subject and glare cars. Use of the Study 2 method would be suitable where target detection distance changes rapidly with glare car distance, illustrated by those parts of the target detection distance curves that have considerable slope. However, reference to figure 9 shows that this condition of rapid change would apply to only a small part of the curves.

A third variation in methodology, which was not performed, would be to have the test subject and the glare car stationary while the target is moved toward the subject. This method is shown as Study 4 in figure 10. With the glare car and subject being stationary, the glare condition would be constant and the distance at which the target could be detected at different lateral separations could be determined for constant glare. Several different distances between the glare car and the subject would be used. The data would then fall along lines of constant distances between subject and glare car and would be represented by the vertical lines in the bottom part of figure 10. This would probably be the best method for obtaining the target detection distances for the parts of the curves that have a shallow slope. For the steeper slope parts of the curve, the points of intersection would be subject to error. The main objections to this study method are the difficulty of moving the target toward the subject and the consequent changes in the environment of the target.

## RECOMMENDATIONS

### *Method*

Although the greatest initial objections were made to the method of Study 1, the use of several relative distances between target car and glare car disposes of these very objections. This method, with the following-described modifications, is therefore recommended for visibility tests based on target detection distance.

In addition to using several relative distances between glare car and target, many test subjects should be used and the choice of subjects preferably should represent a cross section of ages and different degrees of visual ability. There is evidence that older drivers have poorer night vision (*6*) and are affected by glare to a greater degree than those having normal vision (*7, 8*). Note: Vision scores under daylight levels of illumination are not an assurance of the degree of a person's night visual ability (*9*).

The use of one particular target for glare tests would give relations between lateral and longitudinal separations and detection distance for that target only. These relations might be different for different targets, depending on the magnitudes of the distances at which the targets were detectable and at which the different subjects would be able to detect them. Therefore, it is recommended that several critical targets of interest and of varied difficulty be used.

Changing the position of the target transversely across the driver's line of travel is not recommended because this will change the illumination on the target from the driver's own headlights and will change his line of sight with respect to the opposing headlights. It will be shown in the discussion of Study 3 that the background against which the target is viewed has a critical bearing on the detectability of the target. A possible effect caused by light from the opposing headlights reflected from the pavement in the vicinity of the target is also to be discussed. Light from the opposing headlights may be reflected from the target itself. The results of a study by Schwab (*11*) show that, aside from the glare effect, light from opposing headlights has other effects on the visibility of targets. Changes of target position, therefore, may be equivalent to using different targets and, if done, a complete set of data should be taken for each position and analyzed separately. It may be that minor changes in target position across the driver's lane may not be critical when the target can be detected at distances of 500 feet or more. Still, any change in target position will tend to increase the variability of the data.

Because threshold is related to the probability of detection, target detection will be affected by the degree of attention devoted to the task and the degree of expectation associated with the target's presence and location. According to Roper (*10*), objects were detectable at twice the distance when drivers were actively looking for them as opposed to unexpected targets. It is therefore important that all subjects receive the same instructions and use a constant criterion such as "I definitely see it," or "I think I see it," for all tests so that the results can be compared. To reduce guessing and anticipation during the experiment, it is suggested that the target not be present at all times and that the targets be changed at random between runs.

Because it is difficult to determine beforehand where the critical points in the curves exist, such as breaks in the curves and minimum detection distances for each lateral separation, particularly when several targets differing in difficulty are used, preliminary estimates of the relative distance between glare car and target and the lateral separations to be studied should be based on pilot studies in which the same targets are used and the same subjects participate.

Greater efficiency may be obtained in executing the field studies if several test subjects are employed simultaneously. Allowance should be made for any differences in their lateral positions. One possibility would be to have them alternate positions. They could alternate driving and riding in a carefully balanced and random pattern. No subject should be in the back seat of the test car because sometimes the opposing headlights will be blocked by those in the front or by parts of the car itself. One possible disadvantage to this procedure would be the differences in the degree of concentration if one participant drove while the others were able to devote their full attention to looking for targets.

To reduce reaction timelags and promote greater accuracy in the distance measurements, some convenient method of instrumenting the distance measurement and of recording responses should be used; for example, a fifth wheel device for distance measurement and a pushbutton that could be used to record responses by actuating a printout or pen recorder. Regardless of the method used, test subjects must be prevented from influencing each other when more than one is present for a run.

The exploratory studies reported here and studies reported elsewhere have been limited to the situation in which a single opposing vehicle is met. Although this is not an unusual situation, it is perhaps more common for a driver to be faced by several opposing vehicles at a time and at frequent intervals along the highway. It is therefore suggested that the more critical situation of a continuous line of opposing vehicles be tested. The spacing of these vehicles and the number of lanes of opposing vehicles could be varied to simulate different volume conditions and lane configurations. Then, the variable—the distance of the opposing glare car—would be replaced by the level of glare in terms of density of opposing vehicles or veiling brightness. (Veiling brightness is discussed in connection with Study 3.) Inasmuch as the first two exploratory studies have shown that glare effects extend for long distances from the opposing glare car, the line of opposing vehicles would have to extend for considerable distances. Should this not be feasible, shorter lines of opposing vehicles could be utilized, but another variable would be present; that is, distance to the first or last opposing vehicle. It is possible that the difference in glare effect caused by a continuous line of opposing vehicles and that caused by some critical segment of the line may be negligible. To determine the critical segment, if there is one, might require an extensive study.

### *Realistic Conditions*

One further suggestion is made. Because studies of headlight glare made when the cars have clean windshields do not achieve typical realism, perhaps the most critical test should include a car having a dusty windshield. However, problems can be foreseen in trying to maintain a constant condition of dirtiness of the windshield; but perhaps, some method might be developed to simulate the light-scattering properties of a dusty windshield.

### *Detection Distance as a Parameter*

The measurements of target detection distance given here are the maximum possible; they represent measurements at the lowest possible limit of performance—bare detection under conditions in which the test subject is concentrating on detecting something, usually knows what he is looking for, and knows approximately when and where to look for it. These are not realistic conditions for the actual driving situation and compared to the test situation, the subject will be closer to the target when he detects it. At detection, the angular dimensions of the target, visual angles subtended by the visible dimensions, will be greater and the illumination on the target will be greater by the square of the ratio of the respective distances (inverse square law of illumination). For example, if the subject needs to be half as close to detect the target in an actual driving situation as in the test situation, the angular dimensions of the target would have to be doubled and at the same time the illumination on the target would have to be increased four times. By the same token, relative detection distances do not represent the same relative degrees of visibility. It cannot be said that for one set of conditions *visibility* is double that for another set, but only that the *detection distance* for a *particular target* is twice as good. However, in a test situation, the degree of attention and expectation existing in the actual driving situation cannot be simulated, and if usable responses are to be obtained some concessions must be made to practicality.

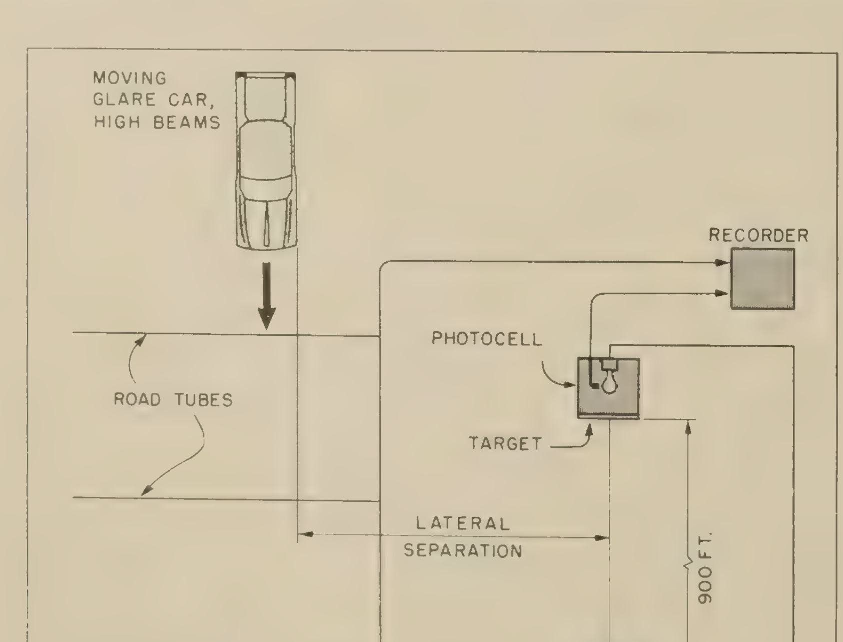


*Figure 11.—Field layout for Study 3.*

The detection distance obtained by taking the average of a number of detection distance observations represents the distance at which the target was barely detected 50 percent of the time when maximum concentration existed. Because relative results are useful, this would be acceptable, if actual driving detection distances were directly proportional to those obtained in the test situation. This appears doubtful, however, because of all the other changes that take place as distance to the target changes. To partially adjust for realism, it is suggested that some higher probability level of detection be shown, such as those distances at which the target is detectable 95 percent of the time. Practical limitations, in terms of the amount of data that would have to be collected, would prevent the achievement of probabilities of detection of more than 95 percent. When it is possible to obtain approximately 100 replications for each condition (one lateral separation, one target, and one setup of glare car and target) the detection distance that is exceeded 95 percent of the time may be taken from a cumulative frequency plot. This procedure is unreliable when the sample size is much smaller than 100 replications. For example, when a sample size is 20 observations, the lowest fifth percentile would have to be based on only one observation. When the sample is smaller than 100, a normal distribution may be assumed or tested for, the mean and standard deviation calculated, and the fifth percentile computed. The larger the variability in the data, the larger the sample size will have to be for reliability.

The problems of relating the results of visibility tests to the real driving situation arise from the use of detection distance as the parameter for ascertaining the effect of opposing glare on visual performance, because the only data that can be obtained are at locations where the target is at threshold. The level of visual performance at other locations cannot be measured. That is, if, under a given set of conditions, a target of interest can be seen—it is above threshold—there is no way of knowing how *well* it can be seen.

The recommendations for this type of study old only for the assumption that these effects n target detection distance are the criteria r evaluating the effects of headlight glare. his is another way of saying that studies of rget detection distance should be performed nly if effects on target detection distance are eaningful, which is questionable. Discuson of some of the other controls and factors importance in visibility tests, such as easures of glare levels and the effects of the reas against which the target is viewed, must e postponed until after the discussion of the ird study.

## STUDY 3

The analyses and interpretation of the sults of Studies 1 and 2 were plagued by the roblems of the dependency of the results on a articular practical target, of possible variaons caused by different headlight aims and fferent positions of the target, and by the multaneous changes in both the illumination n and the angular size of the target as the river approached it. In order to obtain a neral picture of the extent of the glare effect, different approach from the previous ethods was used in Study 3.

The aim was to have a fixed target of onstant size, and to change its visibility by arying its brightness. It was thought that e relative brightnesses necessary to maintain constant level of visibility of the target ould give indications of the relative effects f different lateral separations and of longidinal distance of the opposing vehicle. The nly measure of the level of constant visibility hat could be obtained was the threshold level.

The field layout for Study 3 is shown in figure 11. The target was a 21- by 26-inch white translucent plexiglass screen illuminated from behind by an incandescent lamp. A variable transformer was used to vary the voltage across the lamp and thereby vary the brightness of the target. The voltage induced in a photocell mounted next to the lamp was recorded. A range of brightness readings on the target was obtained by using a Spectra brightness spot meter (*12*) reading directly in footlamberts (lumens/sq. ft.); this calibration was used to transform the recorded photocell output into terms of brightness.

The subject was seated in a stationary car and viewed the self-illuminated target at a distance of 900 feet; the target was situated directly ahead and its center was approximately 3 feet above the pavement. The subject's eye height was 4 feet: the line of sight was, therefore, essentially parallel to both the path of the glare car and to the pavement. The 21- by 26-inch rectangular target, at 900 feet, subtended visual angles of approximately 7 by 8 minutes of arc. The subject's car headlights were on low beam to establish a constant brightness on the pavement and adjacent area that is typical in the normal driving situation.

As the glare car, with high beams on, approached at a speed of 10 miles per hour, the subject used the variable transformer to adjust the brightness of the target so that it remained approximately at the threshold of visibility. He did this by increasing the target brightness until he could just detect the target, then decreasing the brightness until the target disappeared, etc. After some practice he could do this rapidly and with very little hand movement. The resultant oscillations on the recorder tape were at a frequency of approximately 1 cycle per second, and the oscillations were of low amplitude. The average of the peaks and troughs of the oscillations was taken as threshold.

After the glare car had passed him, the subject continued to keep the target at an approximation of threshold while his eyes readapted to the no-glare condition. This was assumed to have occurred when the record of the photocell output reached a constant level. The average of these outputs for all runs for each individual was taken as his no-glare threshold. The longitudinal distance between the subject and the glare car was obtained by means of road tube actuations that were recorded simultaneously with the photocell output.

Runs were made in random order at lateral separations of 7, 20, 32, 57, and 107 feet. The first road tube was located 3,000 feet from the subject, but because it apparently took some time for him to find his threshold level, the data collected for distances of more than 1,800 feet are not considered entirely reliable.

### *Results*

It had been expected that the results of Study 3 would be more clearly interpretable than those of Studies 1 and 2; it was believed that the variables were more exactly controlled and could be measured more exactly. This was partially true, at least in a qualitative sense, and is illustrated by data shown in figure 12. A set of curves is shown for each of two subjects, A and B. The part of the abscissa to the right of the zero distance

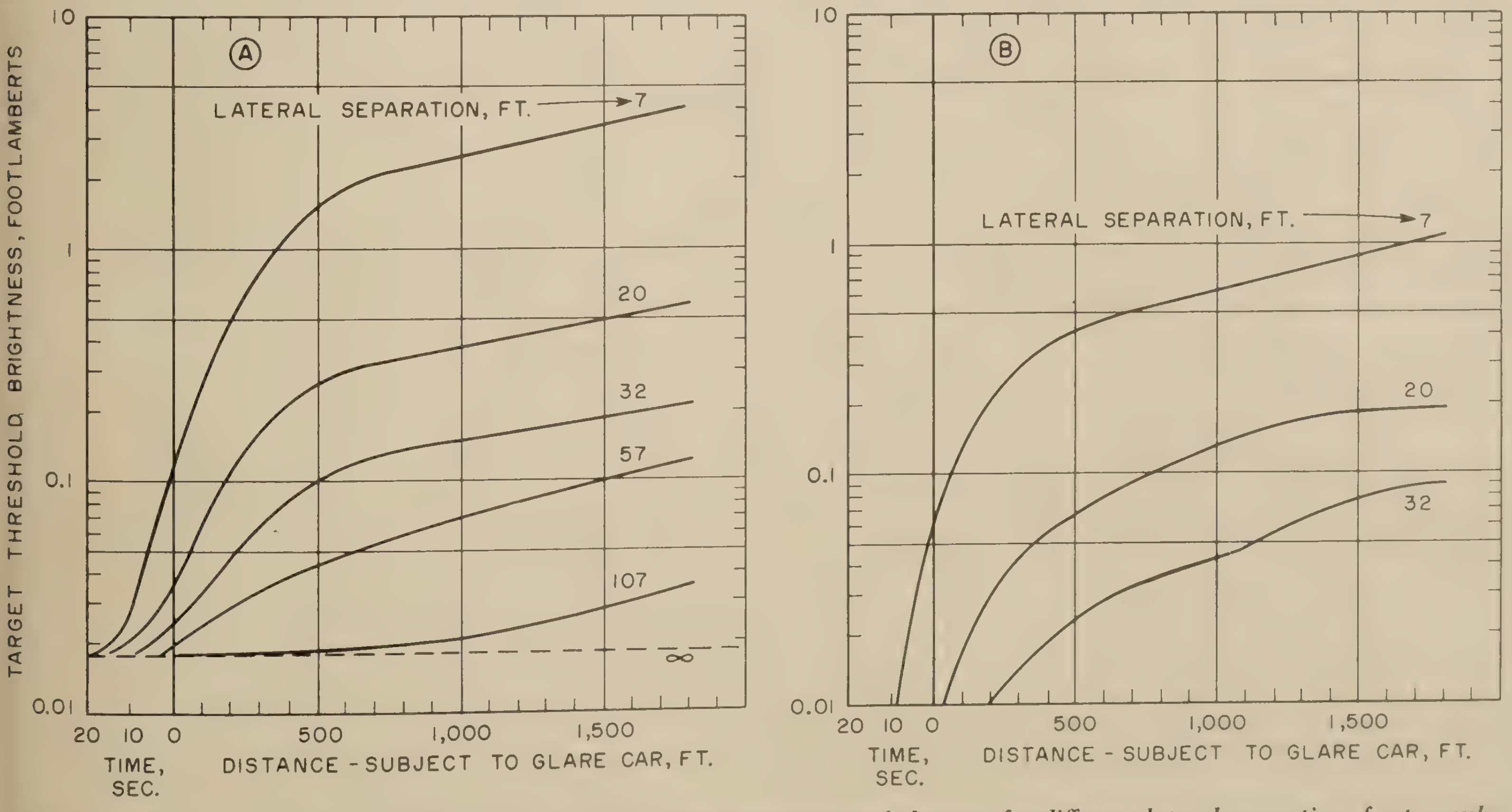


*Figure 12.—Threshold brightness of 8-minute target: variation by distance of glare car for different lateral separations for two subjects, A and B (Study 3). Time scale equivalent to distance scale for 10-m.p.h. running speed of glare car.*

point shows the longitudinal distance between the subject and the glare vehicle; the part to the left shows the time after the glare car had passed. (The time scale shown is equivalent to the distance scale for the 10-m.p.h. running speed of the glare car; that is, 10 m.p.h. is 15 feet per second, and the time and distance scales have been drawn so that a 1-second interval on the former is the same length as a 15-foot interval on the latter.) The ordinate shows the target brightness in footlamberts when the target was at the threshold of visibility for each of the two participants. Each curve is for a different lateral separation and represents the smoothed average of at least three and sometimes four replications.

The interpretation of figure 12 can be visualized, as follows: consider the subject to have been situated at distance zero, facing the glare vehicle as it approached from the right of the figure. As the distance from glare source decreased, the decline in the curves indicates that the brightness necessary to maintain threshold visibility also decreased; that is, the disabling effect of the glare source was apparently decreasing. This was contrary to what had been expected.

For example, in figure 12, part A, for a lateral separation of 7 feet, when the glare vehicle was 1,800 feet away, a target brightness of 4 footlamberts was required for threshold visibility; when the glare vehicle was 600 feet away, only 2 footlamberts were required; and when the glare vehicle was not present, only 0.018 footlambert was required. The fact that all the curves do not approach the no-glare level at zero distance doubtless was the result of the subject's eyes not having readapted to the no-glare condition. The time required for this readaptation is shown to the left of the zero distance point.

These readaptation times are possibly longer than those that occur in the normal driving situation because of the length of exposure. But, the readaptation times obtained also might have been shorter than those in the normal driving situation because of the slowness of the simulated meeting. The driver obviously must be readapting during the time the glare level is dropping as the opposing vehicle is about to pass him. This time period between exposure to the higher glare levels and disappearance of the glare source would be much shorter at normal speeds; readaptation in the normal driving situation would start later and might, therefore, continue for a longer period of time after the glare car had passed the driver. The net effect on the observed adaptation times of these two compensating operations cannot be determined for the test situation of Study 3.

Because the curves represent the smoothed averages of a few replications, there might have been significant changes in slope that could not have been determined because of the limited sample size. As an indication of the variance of threshold brightness among runs—or of the range of brightnesses that approximated threshold—participant A's no-glare thresholds ranged from 0.013 to 0.026 footlambert, or one-third of a log unit. This is comparable to the range in threshold measurements normally obtained in this type of research. Therefore, the no-glare threshold measurements had the least variance among runs of any of the other data collected.

Both subjects of Study 3 had taken part in Study 1: A was one of those who had shown relatively poor nighttime visual performance (*L*) and B was one of those who had been classed as having normal vision (*N*). As shown in figure 12, A required more than half a log unit more brightness to detect the target than B. In order to bring the target down to threshold when the glare car was at the wider lateral separations, participant B required lower brightnesses than could be obtained with the apparatus available. Furthermore, for the no-glare condition he was able to detect the target, without its being internally illuminated, by the light from his own headlights.

## *Psychophysiology of Vision*

An explanation of the results obtained in Study 3 requires examination of the phenomena that are operating, based on a background of the psychophysiology of vision (*13*, *14*).

When one looks directly at an object, light from the object forms an image at the central part of the retina, referred to as the fovea, which is the rod-free area of most distinct vision. Light entering the eye from a bright source away from the line of sight should form an image on the retina away from the fovea. However, because the media of the eye (cornea, lens, etc.) are not perfectly transparent, this light is partly scattered within the eyeball and some of it falls on the fovea, thus raising the adaptation level. The effect is similar to the interposition of a veil of light between the object and the eye and has, therefore, been termed veiling brightness. An equation for the veiling brightness ($B_v$) produced by a point source such as a distant headlight is given by Fry[6] (*15*):

$$B_v=\frac{kE\cos\theta}{\theta(\theta+1.5)} \tag{3}$$

$$E=\frac{I}{d^2} \tag{4}$$

Where,

$B_v$ = veiling brightness, footlamberts;
$E$ = illumination at the eye, footcandles;
$I$ = intensity of the source directed at the eye, candelas;
$d$ = distance of the source from the eye, feet;
$\theta$ = angle between the source and the line of sight, degrees;
$k$ = proportionality factor, 28.9 when the preceding units are used.

An object is detectable because of the contrast of its brightness ($B_o$) to the brightness of the background ($B_b$) against which it is viewed (more correctly, to the level of brightness to which the area of the retina adjacent to the image is adapted). Contrast is expressed by Blackwell (*17*) as:

$$C=\frac{B_o-B_b}{B_b} \tag{5}$$

Because the veiling brightness exists in the eye, its effect is to appear to add to both the brightness of the target and of the background. However, it decreases the effective contrast ($C_e$) because the brightness difference between the object and its background remains unchanged, but the adaptation level (the original $B_b$ plus the superimposed $B_v$) is raised.

$$C_e=\frac{(B_o+B_v)-(B_b+B_v)}{B_b+B_v}$$

$$=\frac{B_o-B_b}{B_b+B_v} \tag{6}$$

Therefore, the extent to which a given magnitude of veiling brightness will reduce visibility will depend on the magnitudes of the existing brightnesses. To further complicate matters, lest it be thought that the contrast required to detect a given size target is constant, threshold contrast varies with adaptation brightness.

## *Target Detection and Veiling Brightness*

From equations (3) and (4) and a candlepower diagram for the configuration of headlamps (system of four lamps set on high beams) used in Study 3, values of veiling brightness[7] caused by the opposing headlights were calculated for each of the lateral separations for the geometric conditions of the experiment. The changes in veiling brightness in relation to the longitudinal distance of the glare car is shown in figure 13. The calculations are for a horizontal line of sight and were based on the assumption that the glare car was traveling in a path parallel to the subject's line of sight on a horizontal plane. The magnitude of the veiling brightness and the shapes of the curves will be different if any of the following given conditions are changed: orientation of the line of sight, highway geometry (affecting the orientation of the opposing headlamps), number of glare sources, or headlight beam (high or low). In addition, the degree of opacity of the media of the eye will differ between individuals. The peculiar shapes of the curves in figure 13 are the result of the way in which the factors affecting veiling brightness changed in relation to lateral and longitudinal separation.

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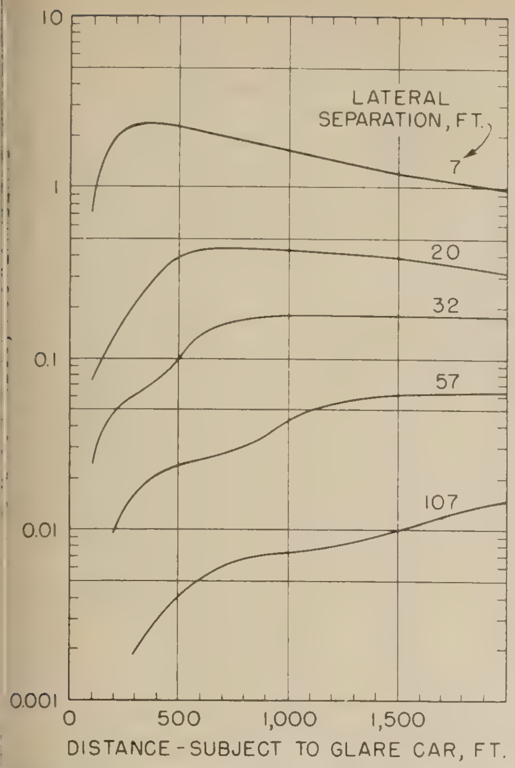
[6] This equation was derived from experiments in which male college students participated. Older drivers might be expected to experience more scattering because of the increased opacity of the media of their eyes (*8*, *16*).

[7] However, veiling brightness can be measured directly by means of the Fry-Pritchard glare lens used in conjunction with a Pritchard telephotometer. This lens, attached to the photometer, measures the veiling brightness from all light sources in the field of view by integrating them according to equation (3). Both this lens and the Pritchard photometer are briefly described in reference *12*. Reference *18* contains a detailed description of the lens.



*igure 13.—Veiling brightness calculated from equation 1 for opposing high beams for conditions of Study 3 (line of sight parallel to pavement and to path of glare car). Each curve is for a different lateral separation.*

The curves in figure 13 were drawn in the same format as those of figure 12; that is, the subject is assumed to be situated at distance zero facing the glare car as it approaches from the right of the illustration. Veiling brightness at the 7-foot lateral separation rose gradually to a peak, as the glare car approached from 2,000 feet to within 400 to 300 feet, and then dropped sharply. Veiling brightnesses at the 20- and 32-foot lateral separations were fairly constant for long distances and began to drop off at about 600 and 700 feet, respectively. Veiling brightnesses for the 57- and 107-foot lateral separations were already decreasing as the glare car approached to within 2,000 feet of the subject.

Candlepower ($I$) used to compute the illumination ($E$) which is then used in the veiling brightness equation (equation 3) are not shown for large angles on the available candlepower diagrams. At short distances, candlepower is very low and the glare angle ($\theta$) is getting so large that veiling brightness becomes very small. Veiling brightness must obviously be zero at zero longitudinal distance of headlights from the subject; therefore, the curves must approach the zero distance line asymptotically on the log scale. Target threshold brightness is related to veiling brightness through the brightness-contrast function, equation (6). Unfortunately, the equipment available at the time this experiment was performed was inadequate to measure the low levels of background brightness that were present at the site, so target contrast could not be calculated. However, *all other things being constant,* target threshold brightness should vary directly with veiling brightness; for example, where veiling brightness is high, target brightness should be correspondingly high.

### *Inconsistencies Noted*

Comparison of the threshold brightness curves of figure 12 with the veiling brightness curves of figure 13 shows that generally the brightness required to keep the target at threshold changed in much the same manner as the veiling brightness. However, there was some inconsistency: for the 7-foot lateral separation, between 1,800 and 300 feet, target brightness was falling as veiling brightness was rising. At lateral separations of 20 and 32 feet, target brightness was falling even when veiling brightness remained fairly constant. Only for the 57- and 107-foot separations did target brightness and veiling brightness decrease concurrently.

A comparison of the Study 2 target detection distance curves (fig. 9) with the veiling brightness curves from Study 3 (fig. 13) shows them to be generally consistent (to visualize this, imagine that figure 9 is turned upside down). For the narrow separations, at glare car distances where veiling brightness was increasing, target detection distance was decreasing, and vice versa. Therefore, the Study 2 target detection distance curves seem to show a different relationship between the effects of headlight glare and position of the glare car than do the target threshold brightness curves of Study 3. Based on the target detection distance, the disabling effect of glare was shown (Study 2) to increase as the glare car approached from far distances, reach a maximum, and then decline as the glare car came abreast of the subject. But, the Study 3 data on target threshold brightness show the disabling effect of glare to be worst at far distances of the glare car (up to 1,800 feet) and to decline as the glare car approached. Further analysis was made of data from Study 3 to investigate whether the differences in the results were the result of differences in the targets and study methods.

It was postulated that if all other things remained constant for different locations of the glare car, then changes in veiling brightness alone should determine changes in the contrast conditions and, consequently, in target threshold brightness. It should follow, therefore, that, when the same veiling brightness occurs for different locations of the glare car, the corresponding target threshold brightnesses should also be equal.

To check the validity of the postulation, the data of figures 12 and 13 have been combined in figure 14 to show target threshold brightness for the associated veiling brightness for each driver, lateral separation, and distance of the glare car. Two sets of curves are shown, one for each driver. The small

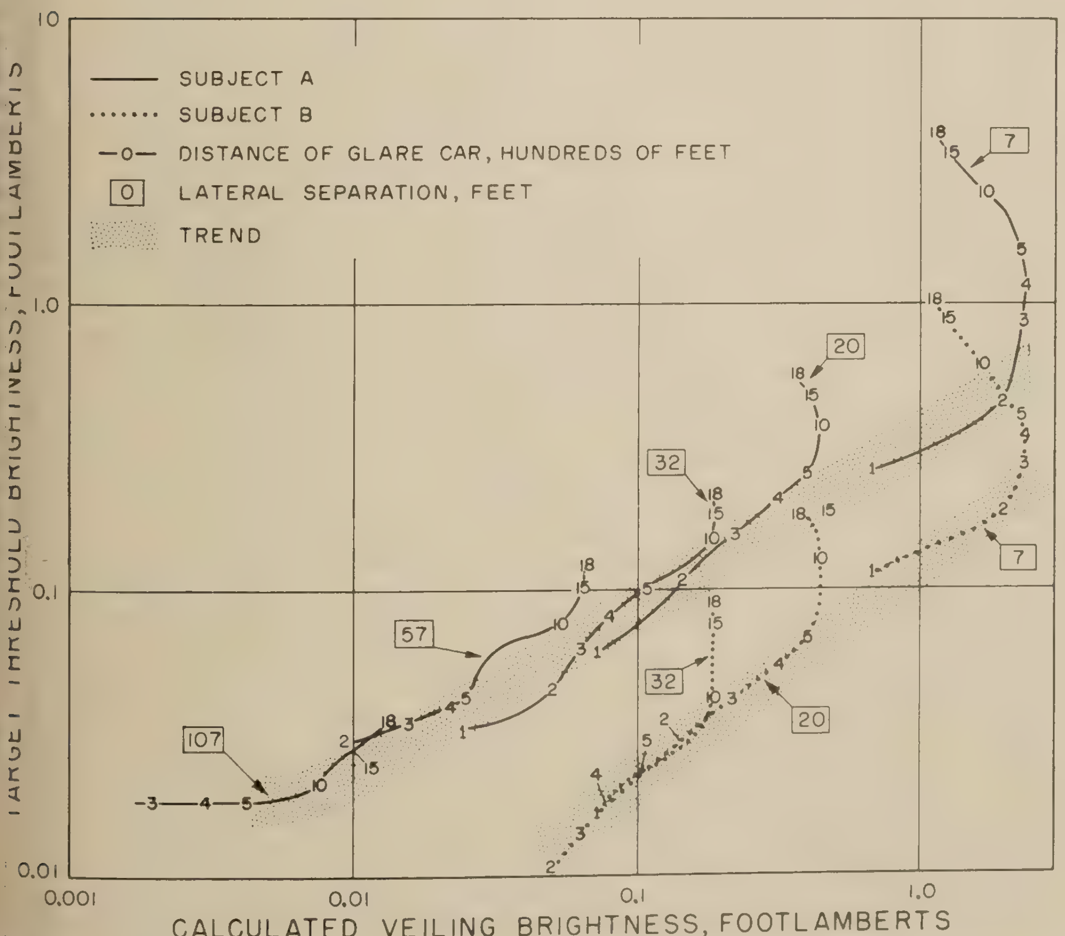


*Figure 14.—Relation of target threshold brightness to calculated veiling brightness for two subjects.*

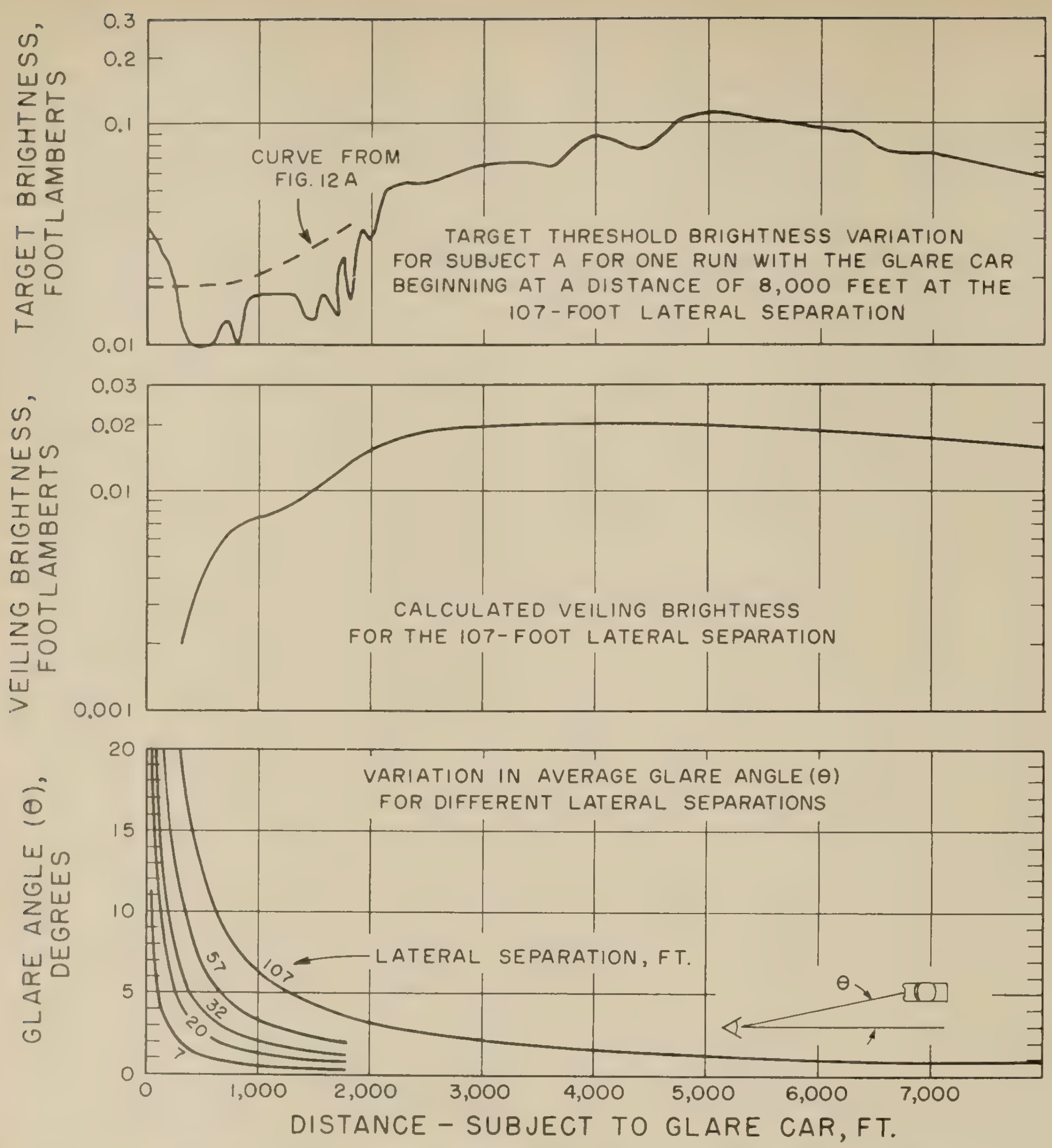


*Figure 15.—Variation of target threshold brightness, calculated veiling brightness, and average glare angle (θ) by glare car distance.*

numerals on the curves are the distances, in hundreds of feet, of the glare car at separations for each curve. If the target threshold brightness is dependent only on the level of veiling brightness and if the calculated veiling brightnesses are correct, all the curves for each subject should overlap. Considering the limitations of the target threshold determinations and the fact that veiling brightness has been calculated rather than measured, the coincidence of the curves for the different lateral separations for each subject is very good. An arbitrary trend line has been drawn for each driver. The curves for each lateral separation have been drawn as far as the available values of veiling brightness would permit. Had very low values of veiling brightness been available for the short distances, all the curves theoretically would follow the trend lines to the no-glare level were it not for the lag in adaptation. This lag may account for the decreasing slope of most of the curves at the short distances.

**Possible sources of inconsistencies**

Although most parts of the curves in figure 14 show a high degree of coincidence, some discrepancies occur: some parts of the curves do not follow the trend lines or the trend slopes. The inconsistencies noted when the target brightness curves of figure 12 and the veiling brightness curves of figure 13 were compared stand out clearly. These departures from the trend lines occur most pronouncedly at the narrow separations and at the long distances from the glare car.

Four conditions that may have been the source of the inconsistencies in the data collected are discussed in the following paragraphs. (As an aid, the reader should attempt to visualize the target and its background, as if he were the test subject.)

- Part of the target, being somewhat closer to the pavement than the subject's eyes, was viewed against a background of pavement. The opposing headlights not only introduced veiling brightness into the eye but also lighte up the pavement near the glare car. In a dition, at long distances there was son specular reflection from the pavement betwe the glare car and the subject. Furthermo for long distances and, particularly, at narro lateral separations, the opposing vehicle w very close in angular distance to the targe Therefore, for these long distances and narro separations, a lighted area of pavement existe close to the target. This would have d creased the contrast for the target, and higher target brightness would have bee required to bring it up to threshold.
- The veiling brightness calculations ha been based on the assumption of a fixed, u wavering line of sight. Presumably the targ was approximately at threshold; therefore, should not have been visible for approximate half the time and so could not be fixated upo constantly. (Even if the threshold brigh nesses derived are not for 50-percent detectio the oscillations in target brightness caused the driver required that the target be und tectable approximately half the time.) Sma eye movements may have intermittent brought the line of sight closer to the opposi headlights, thereby increasing the veili brightness to more than had been calculate It is possible that the test subject may ha occasionally glanced directly at the headlight
- According to Schwab (*11*), forward sca tering in the atmosphere of the light from t opposing headlights is appreciable at sma angles. This scattered light would be simil in nature and effect to the scattered light the eye that produces veiling brightness a would reduce the effective contrast of t target, and thus a higher brightness of targ would be required for threshold.
- It is also possible that the extreme bright headlights, being the only promine objects in the field of view, tended to partia distract the subjects' attention and distu their concentration on the target; as a resu the target had to be brighter. The effects all the conditions described would be prese to some extent in the actual highway drivi situation. The effect of the spillover lig from the opposing headlights onto the pav ment of the driver's own roadway would mediated by the characteristics of the medi and the geometries of the two roadways.

The questions raised previously—as to w the target detection distance curves fro Study 2 data showed a somewhat differe relation between the effects of headlight gla and location of the glare car than do the targ threshold brightness curves developed fro Study 3 data—therefore cannot be answer exactly. It is possible that the answers m lie in some of the differences between t studies. For Study 3, the differences betwe the shapes of the curves for calculated veili brightness and target threshold brightne were attributed to several possible facto Among these were the reduction in targ contrast caused by the area of paveme lighted by the opposing vehicle and t proximity of the opposing headlights to t target. However, in Study 2, part of t background against which the reflectors (the arget) were viewed was the dark car body nd not the pavement. In addition, the arget car was offset laterally from straight head (the angular distance of the reflectors n the right side of the car averaged about ne-half degree away from the straight-ahead osition).

### *8,000-Foot Run*

The target threshold brightness measurements discussed so far have been for glare car istances of 1,800 feet or less. The top part f figure 15 is a plot of the target threshold rightness for subject A for one run—the lat-ral separation was 107 feet and the glare car tarted at a longitudinal distance of 8,000 eet. The glare car moved at 60 m.p.h. to ,000 feet, then was rapidly decelerated to each a speed of 10 m.p.h. at 2,400 feet. A ag grade change in the runway of 0.3 percent xisted at a distance of 2,650 feet from the ubject. The fact that the curve for the small ongitudinal distances fluctuates, and also alls below the average no-glare threshold arget brightness of the other runs for the 07-foot lateral separation, should not cause o much concern. Target threshold brightess fluctuated during the no-glare condition nd, for this particular run, happened to be ow. To illustrate some of the variance in the arget threshold brightness, the curve has not een smoothed very much; only the minor scillations around threshold have been mitted. The fluctuations shown in the top art of figure 15 are probably random and o not represent any significant changes in hreshold.

As illustrated, the target had to be main-ained at a substantial brightness while the lare car was between 8,000 and 2,600 feet om the subject. In other words, substantial lare existed even when the glare car was 1½ iles away. The curve of target threshold rightness from figure 12, part A, for the ame subject and lateral separation, is shown or comparison. Were this curve to be ex-nded, it appears that it would meet the 000-foot curve at about 2,100 feet.

For much of the 8,000-foot distance the arget brightnesses recorded for subject B or this same type of run were too low to be easured. However, from 8,000 to 3,000 et the measured target brightness was about 01 footlambert; a slight rise above 0.01 otlambert was measured between 6,000 nd 3,000 feet; this seems to indicate a rise nd decline in threshold similar to that for ubject A at these distances.

For the 107-foot lateral separation, the iddle part of figure 15 shows the variation ith distance from the glare car headlights calculated veiling brightnesses. Although he shapes of the veiling brightness and target rightness curves are similar for both subcts, the target brightnesses for the far stances are much higher than they should e for the corresponding calculations of eiling brightness at these distances. Therere, it is concluded that the high target ightness thresholds at the far distances ere not produced by glare from the headlights alone, but that the effects of reflected light from the pavement, fluctuations in fixation, or forward scattering in the atmosphere also contributed to the results. The lower part of figure 15 shows the variation in average glare angle $\theta$ (measured to center of glare car rather than to the individual headlights) in relation to distance for the different lateral separations.

## SUMMARY DISCUSSION

The studies reported herein were undertaken with the intention of exploring alternate methods of studying the relationship between headlight glare and median width. Inasmuch as insight into the magnitude and extent of the glare effect and the factors involved was desired, the amounts of data collected were small; therefore, little reliance should be placed on the absolute quantitative results. Furthermore, the quantitative results hold only for the particular conditions studied, such as the geometry of the test situation, target, drivers, and surroundings. The qualitative relations between target detection distance and position of the glare car also were affected by these variables. The tests simulated only one car meeting a single opposing vehicle that had high beams on.

### *Discomfort*

The results of the discomfort test made in Study 1—the only study in which both discomfort and visibility were studied—showed that the data for discomfort caused by glare were too variable, and that discomfort was too difficult to define for a limited study to produce useful results. No relation was apparent between visual and discomfort sensitivities to glare.

### *Target Visibility*

The rear of a black, unlighted car was the target for Studies 1 and 2. The rear, red reflectors were always detected first. A self-luminous target, for which the brightness could be varied, was used in Study 3. The results of all three studies showed that the effects of glare on visibility (target detection) decreased as lateral separation was increased and the effects of the glare were substantial even when the opposing glare car was at a longitudinal distance of several thousand feet. Very limited data from Study 3 indicate that effects of the opposing headlights on visibility may be present even when they are at distances of as much as 8,000 feet from the observer. For any individual lateral separation, the rate of change of visibility related to distance of the glare car was small. Large differences in night visual ability and glare sensitivity may exist between drivers; these differences have been correlated with age by other researchers.

From an analysis of the results of Studies 1 and 2, it was concluded that different relations may occur between position of the glare car and target detection distance for different targets or different drivers. This difference in relation may be caused by the interaction between distance at which detection occurs and level of glare existing at that distance. This occurs because of differences in orientation with respect to the opposing headlight beams at different distances from the glare car.

### *Methods*

The method, which was the one used for Study 1, where the glare car and target are stationary and the subject moves toward the target, provides incomplete information if a single fixed relation between target and glare car is maintained. The stationary glare car and target impose an arbitrary relation between distance of the glare car and detection distance. For future research this disadvantage can be overcome by the use of several different relative distances between glare car and target, and by placing the target both in advance of and beyond the glare car.

The method, where target and observer are stationary and the glare car moves toward the observer, which was used in Study 2, is subject to large errors because the cigar-shaped actual glare disability contours cut the observer's theoretical line of travel at such small angles; many repetitions would be required for any accuracy. In addition, the threshold probability levels are unknown, so it is impossible to determine where to draw the contours in the vicinity of those lateral separations where, for some runs, the target is always detectable for the entire run.

For future research recommendations are made for the performance of detection distance studies, using the modified method of Study 1, including the use of several different types of targets, random orders of presentation, the use of representative observers, and the use of constant criterion for reporting detection (in terms of the observer's confidence of detection); it is also suggested that one of the most critical, realistic conditions would be one in which a driver would be faced by a large number of opposing vehicles on low beam. For a situation even more critical and realistic, a dusty windshield could be used.

The difficulty of interpreting relative detection distances for the purpose of assessing visibility is discussed. This difficulty arises particularly because of the probable lack of proportionality between detection distances under the conditions of attention and expectation existing in the test situation as compared to the normal driving situation. To more nearly approach detection distances that are representative of detection distances in actual driving, it is recommended that the results shown be the fifth percentile detection distances rather than the average. The use of the fifth percentile rather than the average gives distances at which the target is detectable 95 percent of the time rather than 50 percent.

### *Other Factors Affecting Visibility*

In Study 3, subject and target were stationary and the subject attempted to keep the self-luminous target approximately at the threshold of visibility, while the glare car moved toward him. As expected, target visibility increased as lateral separation increased. At the narrow separations, readaptation times to the no-glare condition were in the order of 5 to 10 seconds. Surprisingly, target visibility appeared to increase as the glare car approached the observer, at least for the distances analyzed (1,800 to 0 feet). This result was consistent with the manner in which calculated veiling brightness changed as the glare car distance changed for the wide separations, but not for the narrow separations. Comparison of veiling brightness and target brightness showed that the calculated veiling brightnesses either were not the same as those present in the experiment or that other factors were affecting the visibility of the target. It was conjectured that these other factors, which may have affected both the observer's adaptation brightness and the contrast of the target, were caused by fluctuations in the line of sight, by changes in brightness of the pavement against which the target was viewed caused by light from the glare car headlights, or by forward scatter in the atmosphere of light from the glare car headlights. Other possibilities are that the observer occasionally glanced directly at the headlights or that the headlights, being the only prominent objects in the field of view, had an attention-distracting influence.

Therefore, a report of the location of the opposing vehicle alone is not sufficient to define the visibility conditions. The independent variable should be some measure of adaptation, rather than the number or position of opposing vehicles, or horizontal footcandles. In night visibility research, therefore, account should be taken of all factors that might affect the visual adaptation level so that results may be tied to a common denominator.

## REMARKS

As a basis for an explanation of at least part of the results of Study 3, some aspects of the physiological basis of vision are repeated here. Visual receptors are sensitive to a wide range of luminances. They adapt to the particular levels available, although there is a timelag, particularly when the luminance is decreasing from higher to lower levels. Objects are discriminated by contrast; this contrast is defined as the difference in brightness between the object and the adjacent background against which it is viewed divided by the background brightness, equation (5).

Because the media of the eye are not perfectly transparent, all light entering the eye is somewhat scattered or diffused. When the field of view is dark, this scattered light from high intensity sources can be of appreciable magnitude in comparison to the brightnesses of objects. This scattered light within the eye has the effect of a veil of light, superimposed over the field of view and it varies in brightness according to angular distance from the source of light. The effect of this scattered light is veiling brightness.

The disability glare effect is primarily the result of veiling brightness, which lowers the effective contrast by raising the adaptation brightness while leaving unchanged the difference in brightness between the object and its background. This is shown by equation (6).

### *Highway Brightnesses*

The brightness of an object, as viewed by the driver, will depend on the light it emits, if any, and the light it reflects from the environment, from the driver's car headlights, from other sources such as other vehicles moving in the same direction as the driver, and from opposing headlights. The brightness of the background against which the object is viewed may also be affected by any or all of these sources. Light on the pavement from the opposing headlights may help delineate the roadway alinement ahead of the driver by increasing the contrast between the pavement and the shoulder. This is especially true when the pavement surface has different specular reflection characteristics from the shoulder; this is usually the situation as roadway shoulders ordinarily are unpaved. In addition, specular reflection from the pavement will enhance the visibility of objects seen in silhouette but will reduce the visibility of objects seen in direct light, such as pavement markings.

### *Medians*

The factors that determine visibility, such as veiling brightness or background brightness, will themselves be affected by median features, such as median width. At any given longitudinal distance separating an opposing vehicle from an observer, a greater horizontal separation will cause the opposing headlights to be at a greater angle from the line of sight; lower intensities of light and, consequently, less illumination will be directed at the eye of the observer. The result of both the increased angle and the lowered intensity will be lower veiling brightness. Background brightness will be reduced because less of the forward scattered component of the light will be present along the line of sight and less light from the opposing headlights will fall on the driver's own roadway.

On divided highways in rolling or hilly terrain, independent roadway design frequently is employed for all or substantial portions of the highways. This type of design is usually combined with curvilinear alinement (continuous flat curves), and the two roadways are designed as separate cross sections having independent grade lines. The width of median between the two roads varies along the highway. In general, this design tends to reduce glare by providing sections of wide medians that frequently are covered by natural growth or dense plantings. Sections of earth or rock may be left in the median area. The independent grades also may reduce the glare from oncoming cars. But sometimes the glare problems may be accentuated where differences in the grades of the adjacent roadways are slight or where their
centerlines tend to converge and no barrie
to light exists in the median. In goo
design, such potential problems are locate
during design and, if possible, avoided
otherwise, screen planting is usually specified

**Screening features**

The median features that by interpositio
ameliorate the effects of opposing headlight
can be classed as light obstructors. Th
opposing headlights can be hidden fron
view by earth mounds, solid plantings c
vegetation, solid fences, or fences that bloc
the view of opposing headlights at almost a
angles at which they would be visible—thi
blocking can be accomplished by a venetian
blind type of slat fence or expanded meta
antiglare screen. Partial blockage can b
achieved by a chain link fence, which com
pletely blocks the view of opposing headlight
at small angles only. Thick and continuou
plantings of vegetation in the median ca
block the view of opposing headlights; les
dense plantings may permit intermitten
flashes of light from opposing vehicle
Deciduous plants are not as effective i
blocking headlight glare when they los
their foliage; this difficulty can be overcom
by using evergreens for median planting
Some limited use has been made of translucen
screens that reduce the intensity of the ligl
from opposing headlights by reflecting som
absorbing some, and diffusing the rest.

Other median features may produce und
sirable shadows: (1) light from a vehicle ma
fall on the driver's own roadway; (2) a hig
curb may put the left edge of the paveme
in shadow; (3) a curb may also diminish t
contrast between pavement and media
(4) a low solid barrier may accentuate t
shadowing effect; and (5) guardrail posts a
vegetation in the median may introdu
irregular, moving shadow patterns on t
roadway ahead of the driver.

### *Other Solutions*

Other solutions or aids to overcome t
night visibility problems have been propos
or are in use. Foremost among these h
been the increase in visibility obtained
increasing the ambient illumination and roa
way brightness by means of highway lightin
But, these luminaires may also be sources
glare.

Additional illumination in the driver's fie
of view could be provided easily by increasi
the intensity and angular spread of the hea
lights. This would, of course, greatly inte
sify the glare problem. The headlight gla
problem is the result of the need to provi
light directed along the roadway while at t
same time drivers traveling in opposite dir
tions on the same road face each other's lig
sources. Polarization of headlights has be
proposed as a means of drastically diminishi
the apparent brightness of opposing hea
lights while maintaining or increasing t
efficiency of the light output of the drive
own headlights (*19*). This solution
heretofore foundered on the problems as
ciated with the period of transition betw
partial and complete conversion to polariz

headlights. Changes in conditions since the time this system was last considered may yet enable this solution to be realized (*20*).

A partial remedy for the problem of night visibility on highways has been to increase the reflectivity or luminance of some significant objects of interest in order to make better use of or to overcome the limitations of existing headlight illumination. Examples are: reflectorization of signs and pavement markings, and the use of taillights and rear reflectors on vehicles.

## *Night Visibility*

Opposing headlight glare is a problem because it reduces visibility at night. But visibility at night, even without glare, is not considered good. Therefore, the visibility reducing aspects of headlight glare are a part of and not different from, except in degree of severity, the entire night visibility problem. The night visibility problem can be defined, superficially, as a lack of sufficient light. But what is it that requires sufficient light and what are the results of the lack of light. In other words, what needs to be seen. This need would depend on what visual information is used by the driver in the performance of the driving task. Unfortunately, knowledge as to these information needs is limited, as is an appropriate definition of the major aspects of the driving task itself. As additional information for definition of the driving task is obtained, it is believed that more definite information can be obtained as to the drivers' requirements for light.

In the meantime, speculation may prove fruitful in suggesting additional lines of approach to the problems. Apparently sufficient light presently is being provided for the visual task to enable the night-driving task to be accomplished. This can be stated with some degree of confidence because, for the most part, drivers do succeed in accomplishing the task. However, all this may prove is that human beings are highly adaptable; perhaps the task could be accomplished with more of a margin of safety and comfort. What appears to be lacking is a reliable quantitative measure of the degree of adequacy of visibility for the night driving ask; this in turn is the result of a lack of understanding of what constitutes the task.

Detection or visibility of targets at threshold has been emphasized in previous research, perhaps because this is the easiest thing to measure and appears to have the most direct bearing on the visibility problem. The problem of interpreting detection distances has been discussed previously, as has the limited applicability of absolute threshold data to he actual driving situation.

Several instruments have been developed or use in attempts to assess the visibility of objects at suprathreshold levels: two of these instruments are the visual task evaluator (*12, 21, 22*) and the Finch visibility meter (*12, 23*). However, even the visibility data obtained by use of these instruments must e evaluated by arbitrary criteria. In addition to suprathreshold measurements, these instruments permit study of a large variety of types of targets. For example, observations are not limited to targets that are discrete objects. Selected portions of a continuous target such as a pavement edge may be studied. However, the presence in the roadway of objects that may be struck is rare, as differentiated from objects of interest such as pavement lines.

Consider the following hypothetical set of conditions: (1) The driver is confident that no objects except other vehicles are in his path of travel; (2) all vehicles are sufficiently lighted and marked so as to be detectable even under severe conditions of opposing glare. Even with these conditions, a night visibility problem would exist. The driver would still have to be able to see the roadway to obtain information for steering and lateral position control and for judging the location of other vehicles relative to his path of travel.

There are indications that a driver's judgments for steering and position in lane, as well as judgments of his relative speed and position with respect to other vehicles and objects, are determined by his judgments of angular velocities, and that the distance ahead at which these cues are detected is proportional to his speed (*24*). If it is therefore necessary for the driver to detect these cues at some distance ahead, he would be required to reduce his speed under conditions of poor visibility. Should he desire to maintain the same speed as under good visibility conditions, some compensation probably must take place and he may have to devote more concentration and attention to the task of retrieving information. The result may be increased tension and fatigue, but little or no measurable effect on gross driving performance. It is also possible that the driving task might be easier if the driver could determine the course of the roadway farther ahead than is necessary to detect steering cues; thus the driver would be relieved of part of the vigilance task.

On the basis of subjective experience, it seems that, even where the glare effect on visibility is small, such as where a wide median exists, the presence of opposing headlights is annoying. Allied to the problem of the increased vigilance required when visibility is poor is the possibility that the awareness of a deficiency in visibility and the ensuing uncertainty of detecting cues may themselves induce tension. Because man is by nature a daytime animal, the mere presence of darkness may be psychologically depressing.

A driver's attention from the primary visual task of driving may be distracted by opposing headlights or other sources of high intensity illumination such as luminaires, advertising displays, or lights associated with roadside business establishments because they tend to be the brightest and most prominent objects in the field of view. This would be in addition to the decrease in attention stemming from the effect of glare on the contrast of the task. The result of this distraction (noise) could be reduction in visibility caused by the psychological effect in addition to the physiological effects. As another aspect of the problem of the intensified vigilance required, these additional light sources could add to tension and fatigue. In addition to the psychological stress and discomfort engendered, continued exposure to bright headlights may be physically discomforting.

Perhaps the major benefit to be gained by the elimination of high intensity glare sources from the drivers' field of view will be in the drivers' comfort. Therefore, increased emphasis may be warranted on investigations of the relationships between glare and visibility and their relationship in turn to comfort and fatigue.

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# New Publications and Films

### *Introduction*

A new publication and two new 16-mm. motion pictures have recently been completed by the Bureau of Public Roads. *Highway Statistics, 1963,* may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, for $1 prepaid. Prints of the two films: *Sand Drains—Theory, Design, and Construction* and *Spur Dikes* may be borrowed from the Bureau of Public Roads upon a request submitted directly to the Photographic Section, Bureau of Public Roads, Washington, D.C., 20235. There is no charge for the loan of these films, but express or postage fees must be paid by the borrower. Requests should be submitted well in advance of the desired screening date, and alternate dates indicated, if possible. After each booking, immediate return of the film is required.

### *Highway Statistics, 1963*

*Highway Statistics, 1963,* a 157-page publication, is the 19th in the annual series that presents statistical and analytical tables of general interest on motor fuel, motor vehicles, highway-user taxation, State and local highway financing, road and street mileage, and Federal aid for highways. Some of the previous annual issues of the series and the summary to 1955 are also available from the Superintendent of Documents; a list of available issues and their purchase prices is carried on the inside back cover of this magazine.

### *Sand Drains—Theory, Design, Construction*

At the request of the Materials Division, Office of Research and Development, a 16-mm. color film that has an optical sound track and a running time of 25 minutes has been produced by Public Roads. The Office of Engineering and Operations cooperated with the Materials Division in planning the film *Sand Drains—Theory, Design, Construction* and approved its technical content. This movie contains a description of sand drains, including the theoretical aspects of their design and construction. The film was shot on a section of Interstate Highway 495 near Alexandria, Va. This movie was filmed primarily for use in the Public Roads engineering training program. It is also expected be of interest and help to other highw engineers and civil engineering students.

### *Spur Dikes*

Sponsored by the Hydraulics Branch of t Bridge Division in the Office of Engineeri and Operations, *Spur Dikes,* a new 16-m color film, has an optical sound track and running time of 15 minutes. Animated a work, scenes of laboratory models operati under flow conditions, and of an existi spur dike under unusual flood conditions included in the movie. The scenes of op ating models were filmed during research spur dike models at Colorado State Universi sponsored by the Alabama State Highw Department and the Mississippi State Hi way Department in cooperation with Bureau of Public Roads. Also included the film are scenes, made during a major flo of the performance of a field installation on Susquehanna River at Nanticoke, Pa. P and cross section views of the shape and s recommended for spur dikes by the Bur of Public Roads are also included. Use this movie is expected to be helpful in train highway and bridge engineers in the des and construction requirements for spur di

# Moving Picture Technique for Highway Signing Studies—an Investigation of Its Applicability

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**Highway Research Engineer,**
**Traffic Systems Division**

*BY THE OFFICE OF*
*RESEARCH AND DEVELOPMENT*
*BUREAU OF PUBLIC ROADS*

***Establishment of the feasibility of motion picture laboratory tests as a substitute for field research on highway signing was explored in the study reported in this article. Heretofore research related to highway signing generally has been in the form of field tests—a procedure doubly costly in collection of data and research time. Field research is hampered by changing weather conditions, variation in light, interference from traffic, and difficulties associated with obtaining a suitable test site. Development of a suitable laboratory test, it was believed, would eliminate these problems and also permit additional control of variables that might affect the results.***

***The study reported here was undertaken to validate the substitution of the laboratory tests, in which a moving picture technique was used, for the more commonly used field research. Comparisons of results of field and laboratory tests are reported for the mean legibility distances of signs having two, four, and six legends. The number of errors made by the test participants, the possible effect of their guessing, and the effect of the length of the test word were investigated.***

***Results of the study established that a laboratory test can be substituted for field tests if the researcher is interested in determining functional relationships between variables. If absolute values are desired, a correction factor must be applied to the laboratory data if they are to reasonably represent field conditions.***

## *Introduction*

WHEN construction of the National System of Defense and Interstate Highways was approved in 1956, interest increased n American signing practices. Many promnent engineers expressed the need for signing practices that would keep pace with advances n geometric highway design.

The American Association of State Highway Officials has published a standard for signing ighways in the Interstate System, and the National Joint Committee on Uniform Traffic Control Devices has issued a manual in which n entire section is devoted to expressway igning. Many of the design elements inorporated into the signing standards are the results of professional judgment and not research. Although these standards are genrally adequate, a need remains for continuing research that will determine the signing requirements for highways and fulfill the needs of motorists.

An extensive research program is required to provide insight into the many complex variables involved in the design of highway signs. A program of this magnitude requires that research manpower be used efficiently and economically. It is impossible to determine with certainty what constitutes efficient and economic utilization of research manpower, but a brief summary of past and present research methods may provide a useful perspective.

Research in the field of highway signing generally has been in the form of field studies in which large amounts of data were collected at considerable cost and, probably more important, at the expense of considerable time of the researcher. Field variables were usually difficult and sometimes impossible to control. Hindrances to research included the unpredictability of the weather, changes in light conditions, interference from traffic, and lack of a suitable test site at the time it was needed. The result of such postponements is an inefficient use of the researcher's time. Although the foregoing is an oversimplification of the research problem related to signing, it does demonstrate that conducting a field study on signing requirements is not as simple as it might appear to be.

A laboratory study on signing would eliminate weather, light, and traffic problems; reduce site selection difficulties; reduce the time required for obtaining data; and provide the researcher with additional control over the variables. A moving picture technique in which a 16-mm. color film would be used appeared to offer the greatest promise for a successful laboratory study. Such a technique was employed by Burg and Hulbert (*1*)[2] with apparent success in a study made in California.

Some researchers are satisfied that the substitution of a laboratory for a field test will provide representative results, but others are skeptical because validation has not been established. The study reported here was undertaken to validate the substitution: it was performed by comparing results of field and laboratory studies on legibility distances for signs having two, four, and six legends.

## *Conclusions*

The following conclusions have been drawn from the analysis of the study data:

A laboratory test can be substituted for a field test of highway signs if the researcher is interested in determining functional relationships between variables. But, if absolute values are desired, a correction factor must be applied to the laboratory data if it is to reasonably represent field conditions.

Based on the test information and the analysis of the data, it is concluded that the motion picture technique offers much promise as a useful research tool in the evaluation of highway signs; and that further efforts at perfecting, validating, and applying the motion picture technique are warranted.

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[1] Condensation of a thesis submitted to the Bureau of ighway Traffic, Yale University, May 1963.

[2] References indicated by italic numbers in parentheses are listed on p. 147.

### *Study Site*

A completed but unopened section of Interstate highway readily accessible from Washington, D.C., was selected as the site for the field study. The section is a four-lane, divided, portland cement concrete freeway that has lanes 12 feet wide and asphaltic concrete shoulders 10 feet wide. The design speed is 70 m.p.h., maximum curvature is less than 1 degree, and maximum gradient is less than 3 percent. The site is approximately 1 mile long and is free of sight restrictions.

### *Experimental Design*

The 1-mile advance warning sign (*2*) employed on Interstate highways was used as a guide in designing the test signs. For the 1-mile sign, legends are composed of 16-inch Series E capital letters and 12-inch lowercase letters; the resultant sign has an overall dimension of 15 by 11 feet. Use of a sign of this size would have caused considerable difficulty in sign erection and in message rearrangement. Therefore, ⅓-scale letters were used for the signs in the study reported here. The signs were each 60 inches high and 40 inches wide; the letter heights were 5.3 inches for Series E capital letters and 4 inches for lowercase letters. A vehicle test speed of 20 miles per hour was selected to permit the driver about the same time for reading the sign that he would have had for reading the standard sign when traveling 60 miles per hour.

Hulbert and Burg (*3*) determined that the recognition distance for signs on which word lengths are unequal is longer than for signs on which all the words are of equal length. They also determined that the degree of observer familiarity with the legend is an important factor in identifying a message. To eliminate the effect of these variables from the study discussed here, only six-letter words composed of two, three-letter nonsense syllables were used. The nonsense syllables were pronounceable and had an association value in the range of 27 to 47 percent (*4*). Association value is a measure of the relative ease with which the nonsense syllables suggest words. Any range of association values could have been selected as long as all the test words came from the same range.

Another determinant of legibility distance is the composition of letters that form the word. Neu (*5*) assigned the letter E a legibility value of unity and established the legibility of the other letters of the alphabet in relation to E. The values of legibility that he obtained were used to equalize the relative legibility level of each of the test words selected for this study. The summation of the legibility values of each letter comprising a test word was equal to 6.50 ± 0.01. Neu's article contains a detailed discussion on values of legibility for test words.

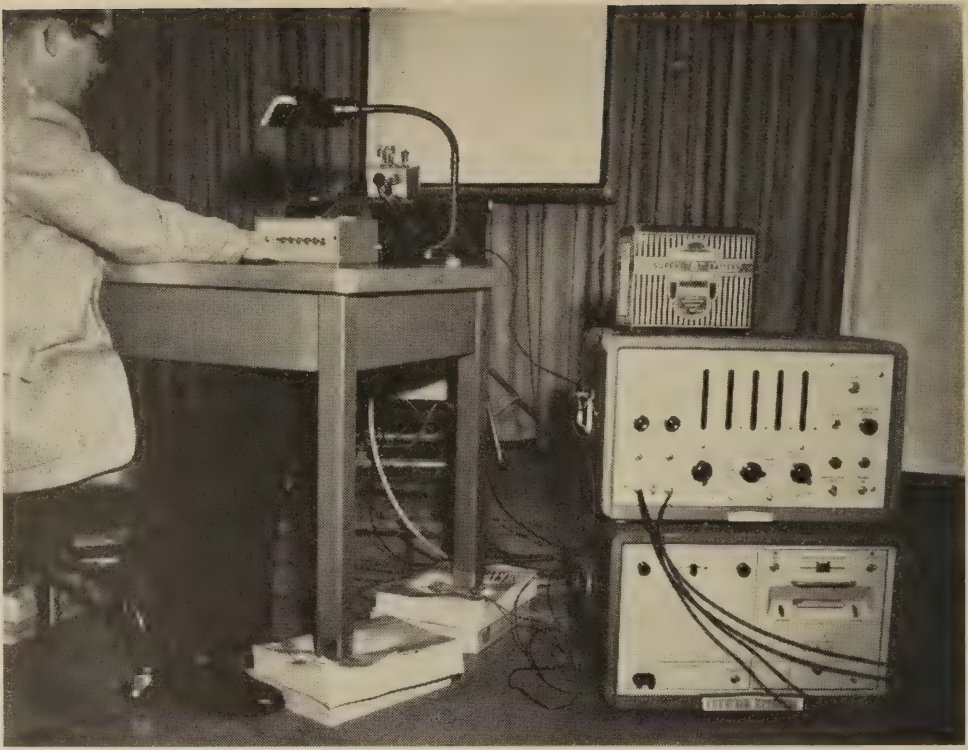

***Figure 1.—Test participant operating laboratory instrumentation: keyboard on tabl at left, digital recorder at lower right below the digital timer.***

The position of a word on a sign in relation to the total message is a factor that affects the test participants' ability to locate the word (*6*). A word on the first or last line of a list-type destination sign is located sooner than one in the center of the sign. Therefore, the test words selected for this study, Dahyum and Ruklah, were positioned to balance this effect. The test word was placed in each position on the two- and four-legend signs and in positions one, three, four, and six on the six-legend signs. The test word was not used in positions two and five on the six-legend sign because the increased accuracy that would be obtained did not justify the extra signs needed. Each observer viewed four each of the two-, four-, and six-legend destination signs. An average of these four observations provided an estimate of the observer's legibility distance, which was independent of the word positioning on the sign.

In addition to the 12 signs on which the test words were used, 3 signs that did not have the test words on them were used in the study reported here. These signs, hereafter referred to as blank signs, were used to evaluate the effect of any guessing by the observers. Five other signs were used as an introductory run in which the participants practiced the test procedure. Accordingly, 20 test signs were shown in random order in four runs of a five-sign test course.

All test participants were Junior Engineers in the Bureau of Public Roads Training Program; their ages ranged from 22 to 35 years, and all had average visual acuity (20/20 to 20/40)—some of the engineers had their vision corrected with glasses. The 60 engineers were divided into two equal groups, the first 30 were participants in the field test and the other 30 were assigned to the labor- tory test.

### *Field Test*

Test sign locations were spaced 1,000 f apart and located 10 feet from the right ed of the pavement. Distances along the ro from the face of the sign were marked coded plates to prevent the participant fr cuing on the plates by memorizing th order of presentation. This cuing co easily have been accomplished if the pla had been presented in numerical or alphabe- cal order.

Three cars, each equipped with calibrat speedometers marked for a true 20 miles p hour, were used in the test. Each engin drove through the course in one of the t cars, an observer was also in the test car. T observer noted and recorded the distance which the participant read the proper des- nation and the line on which he indicated t it was located.

A member of the field test group stayed each sign during the tests to rearrange t messages between test runs. The messag to be placed on the sign boards, were on in vidual cardboard plates and could be eas interchanged. Each plate was hung on ho that had been secured in the proper posit before the test was started.

Complete data for each of the two-, fo and six-legend signs were collected in the f test for 28 test participants.

### *Laboratory Test*

A previously filmed 16-mm. color mov picture of the 20 study signs was used in laboratory test. The order of presentat

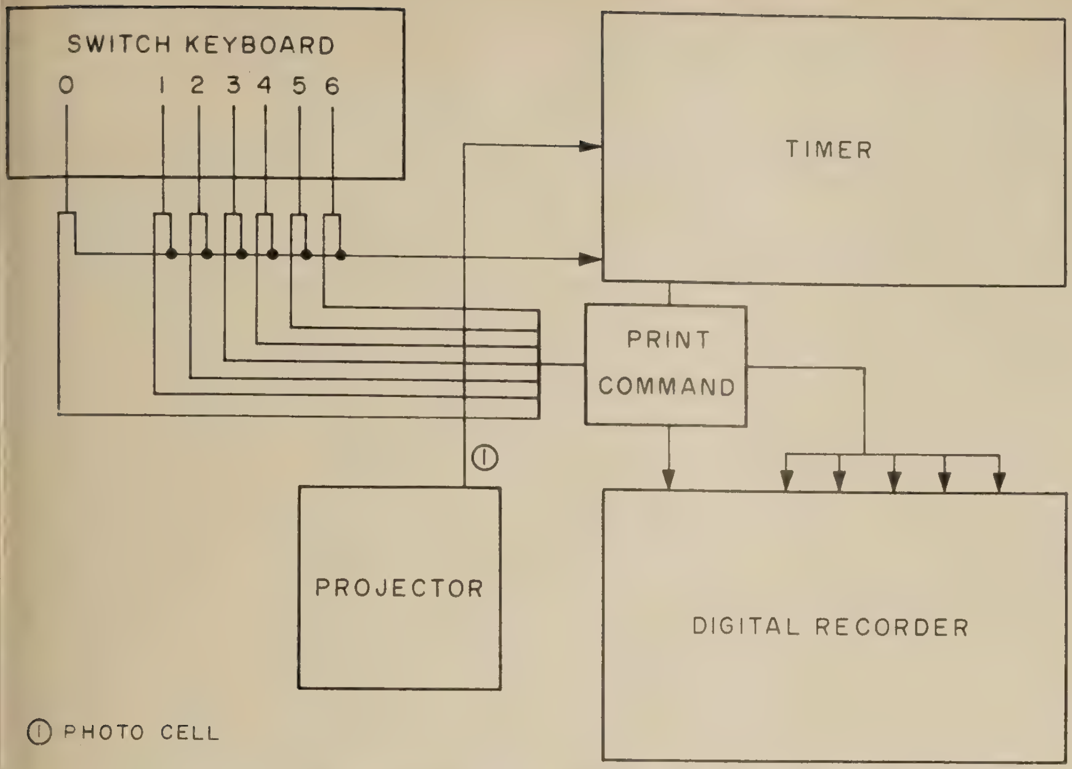

*Figure 2.—Block diagram of laboratory test instrumentation.*

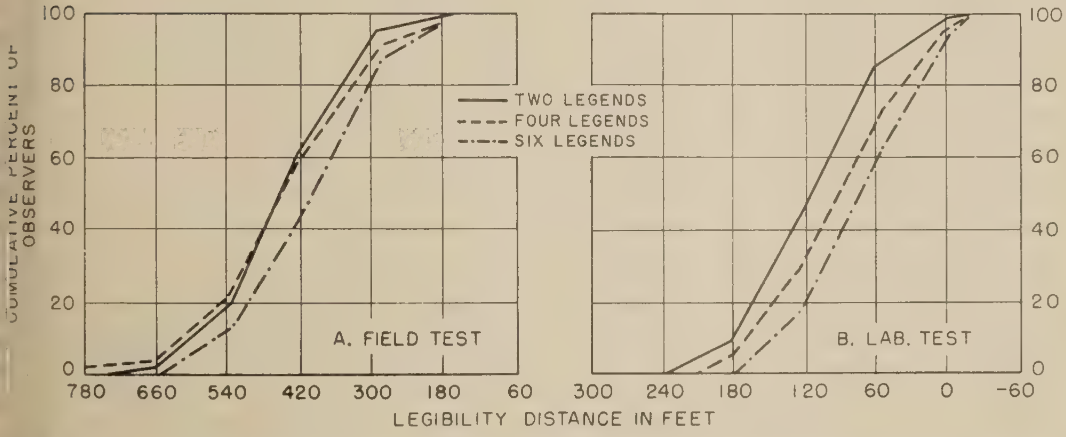

*Figure 3.—Cumulative frequency curves for observers legibility distances for the test word Dahyum on signs having two, four, and six legends.*

as identical to that employed for the field st. Equipment used in the laboratory tests shown in figures 1 and 2. The test partici- ınt was seated behind a table that had been aced 6 feet in front of and 2 feet to the right the screen. A control box (switch key- oard) was mounted on the table and cables nnected it to an electronic timer and a gital recorder. A timer-actuating box, con- sting of a light sensitive photocell and a ntact relay, was focused on the screen.

The use of this equipment is best explained examining the steps involved in a hypo- etical test case. Prior to beginning the test, e following instructions were read to the rticipant: "You will be shown a film, hich is composed of 20 highway signs. Each gn will have from two to six destinations ted on it. You will be required to follow assigned destination throughout the film. is destination may or may not appear on y given sign. You will indicate this by depressing the proper switch, one through six for lines one through six, or zero if your destination does not appear on the signs. You should make your selection as soon as you can read the sign. Your assigned destination is Dahyum."

The 16-mm. color film was then started and at a point 480 frames (approximately 600 feet) in front of the sign, a blank frame, which had previously been inserted, actuated the light sensitive photocell that sent a starting voltage to the timer. When the participant decided on which line his destination was located, he depressed the proper switch—one through six, or zero if the destination were not on the sign. Depression of the switch stopped the timer; the time, to the nearest millisecond, and the number of the switch depressed were automatically recorded on a digital recorder. The film was continued and another sign came into view, whereupon the procedure described was repeated.

**Table 1.—Summary of analysis of variance for the differences between 4- and 6-legend signs**

| | Sum of squares | Degrees of freedom | Mean square |
|---|---|---|---|
| FIELD TEST [1] | | | |
| Source of variation: | | | |
| Between number of legends | 191 | 1 | 191 |
| Between observers | 434 | 54 | 8 |
| LABORATORY TEST [2] | | | |
| Source of variation: | | | |
| Between number of legends | 8 | 1 | 8 |
| Between observers | 67 | 50 | 1.3 |

[1] The F, ratio for the field test was 23.6, and the significance level was 0.01.

[2] The F, ratio for the laboratory test was 7.3, and the significance level was 0.01.

The elapsed time from the blank frame to the moment the observer closed the switch was subtracted from the total time between the blank frame and the sign to determine the elapsed time between the closing of the switch and the passage of the sign. In the laboratory test, complete data for each of the two-, four-, and six-legend signs were collected for 26 test participants.

## *Statistical Analysis*

A normal distribution curve was fitted to the data by means of a chi-square goodness of fit test. The cumulative curves shown in figure 3 did not significantly depart from a normal distribution (0.05 level). The 0.05 level of significance indicates that there are no more than five chances in a hundred that a fit as good as this could have occurred by chance alone.

Once normality had been established, it was possible to employ the standard deviation to determine the minimum sample size for the desired level of confidence and degree of accuracy. The level of confidence selected for this study was 95 percent and the desired degree of accuracy was 10 percent of the mean observed legibility distance. As the largest standard deviation obtained was used in this determination and the required sample size of 22 participants was less than the 26 and 28 participants used in the laboratory and field tests, respectively, it was concluded that the sample size of observations obtained was sufficient for the level of confidence and degree of accuracy desired.

The sample size being sufficiently large to provide the desired degree of accuracy, the statistical significance of the observed differences between two-, four-, and six-legend signs for the field and laboratory tests remained to be established. The analysis of variance was selected for this determination, as it is a powerful tool for evaluating differences between means (*3*). Further, each test was subdivided and the significance of the differences between two- and four-legend signs were analyzed separately from the four- and six-legend signs. In both the laboratory and

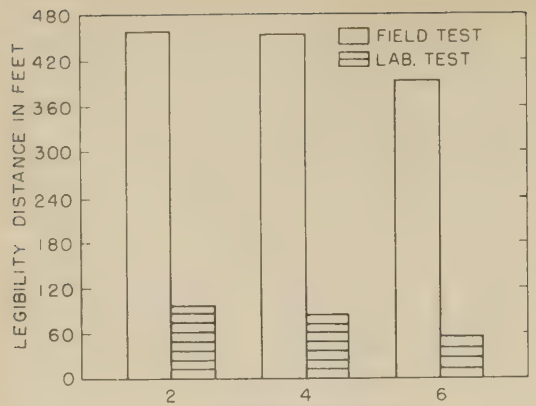

*Figure 4.—Mean legibility distances at which participants could accurately identify the test word in field and laboratory tests.*

field tests, significant differences in means between four and six legends were noted, but none were found between the two- and four-legend signs. The significant data are summarized in table 1.

## *Results*

The mean legibility values for two-, four-, and six-legend signs were plotted against the number of legends for both the laboratory and field tests as shown in figure 4. The laboratory test results had the same functional relationship as the field test results but a considerable difference existed between the absolute value of legibility distances for the two tests. This difference would not have been a serious problem if the objective had been to determine the maximum desirable number of messages on a sign; both tests had identical results in terms of functional relationships. However, if the objective had been to determine the absolute legibility distance of the sign message, a correction factor would have been necessary to obtain agreement between the results of the two tests. The legibility distances for the field test were approximately five times as great as the corresponding laboratory test results. Better agreement in results could probably have been obtained by improving the quality of the pictures in the film used for the laboratory test.

It was noticed during the test, in spite of all the precautions taken, that the test word Dahyum had characteristics causing it to stand out from the other words. Most serious among these characteristics was its length. The width of the letters and the required letter spacings combined to make this word approximately 6 inches longer than the other words on the sign, as shown in figure 5. This effect was more noticeable in the field test than in the laboratory test and could have contributed to the high ratio obtained between the two tests. The effect of the word length will be discussed in greater detail later.

A comparison of the mean legibility distances obtained in the study reported in this article, 110 and 23 feet per inch of *loop height*, respectively, for the field and laboratory tests, with those obtained in other studies indicates that the field legibility distances are somewhat high and the laboratory legibility distances considerably low. In 1957 the Bureau of Public Roads conducted an extensive sign test in Riverdale, Md., and obtained a mean legibility value of 100 feet per inch of *loop height* for 12-inch, lowercase alphabets. Because the average age of the observers was somewhat greater than the ages of the participants in the study discussed here, the sligh lower legibility value is to be expect

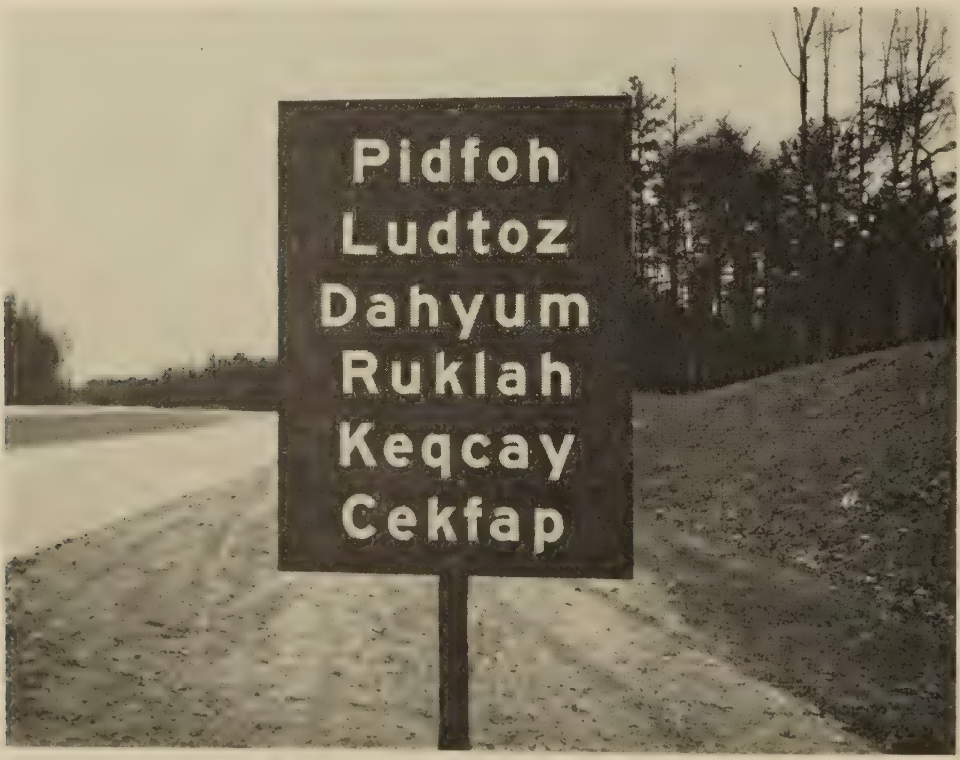

*Figure 5.—The six-legend destination sign, which shows the comparatively longer key word Dahyum.*

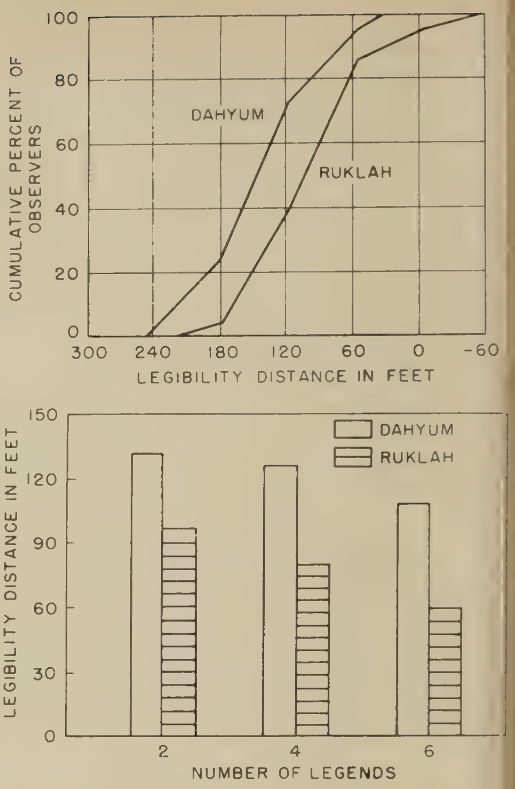

*Figure 6.—Comparison of laboratory t results for key words Dahyum (long) a Ruklah (average length). The top part the figure shows cumulative frequen curves for legibility distances for tw- legend signs. The lower part of t figure shows mean legibility distances f two-, four-, and six-legend signs.*

### Effect of word length

To evaluate the effect of word length, laboratory test participants were asked locate the word Ruklah as well as the w Dahyum. Ruklah is an average length w but, as previously stated, Dahyum approximately 6 inches longer than the aver word length. A comparison between mean legibility distances of each word shown in figure 6. The longer word cau a greater mean legibility distance than normal length word. However, the relat distances between points for either word w almost identical. The frequency distribut curves further support these findings.

Next, the number of observation er made by each participant were examined each word. An error was recorded when word was indicated to be on a line ot that the correct one. The percentage er for each word are summarized in table For either word, the percentage errors creased with an increase in the number legends on the sign. However, considera fewer errors were made for the longer w Dahyum. This was especially true on six-legend signs for which approximately percent of the Ruklah observations w incorrect.

These findings are in agreement with general findings made by Hulbert and B- in 1957 (*3*). They reported that more er

**able 2.—Laboratory test (Dahyum versus Ruklah) percentage error**

| Legends | Error for— | |
|---|---|---|
| | Ruklah | Dahyum |
| *Number* | *Percent* | *Percent* |
| 2 | 12.9 | 3.7 |
| 4 | 18.2 | 6.2 |
| 6 | 42.4 | 7.8 |

**ble 3.—Mean legibility distances for the test word Dahyum and for the blank signs**

| Legends | Mean legibility distance for— | |
|---|---|---|
| | Dahyum | Blank sign |
| LABORATORY TEST | | |
| *Number* | *Feet* | *Feet* |
| 2 | 94 | 78 |
| 4 | 85 | 39 |
| 6 | 56 | 24 |
| FIELD TEST | | |
| 2 | 436 | 407 |
| 4 | 432 | 345 |
| 6 | 396 | 322 |

re made on four-legend than on two- and ree-legend signs. Also, they determined at the probability of the sign being missed s greater when the messages were all of ual length than when the lengths were equal.

**ank sign analysis**

Blank signs, that is, signs not having the t word present, were introduced into the dy to evaluate the effect of guessing by e participants. It was hypothesized that, the participants guessed, proportionately re errors would be made on the blank ns than on the signs on which the test word peared. Also, it was believed that a decrease in legibility distance would be obtained if the participants did not guess but spent more time determining whether the test word was on the sign. Examination of the data showed that less than 1 percent of the blank sign observations were in error. This was considerably less than the 3 to 8 percent of errors previously mentioned for the test word Dahyum.

The mean legibility distances for the blank signs were compared with those obtained for Dahyum; the results are tabulated in table 3. The means for the blank sign were consistently less than the means for the test word Dahyum. This may be explained by an increase in the reading time required before the participant could be sure that his test word was not on the sign. Because few errors were made for the blank signs and the resultant means were considerably less than for the test word, it appears that under the terms of the hypothesis, guessing did not materially affect the results of the study.

## *Summary of Findings*

For both the field and laboratory tests, a decrease in legibility distance was obtained when the number of legends on the sign was increased from four to six. No differences were obtained when the number of legends was increased from two to four.

The number of observation errors made by the participant increased as the number of legends was increased for both test conditions.

In the laboratory test, a test word destination longer than all the other words on the sign, which were equal in length, produced a substantial reduction in the mean observation distance and the number of participants' observation errors.

Guessing by participants did not materially affect the results of this study.

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# Motor-Vehicle Travel Estimates

## 1963 United States
## 1962 State-by-State

*BY THE OFFICE OF PLANNING*
*BUREAU OF PUBLIC ROADS*

**By THEODORE S. DICKERSON, JR., a**
**IVANO E. CORVI, Highway Enginee**
**Current Planning Divisi**

MOTOR-VEHICLE travel in the United States in 1963 totaled 801.1 billion vehicle-miles, an increase of 4.5 percent over the travel in 1962. The travel data were compiled by the Bureau of Public Roads from information supplied by the State highway departments and toll authorities. Total travel for 1964, based on information for the first 10 months of the year, is estimated at 838 billion vehicle-miles, a 4.6-percent increase over 1963.

The proportions of travel by road system and vehicle type changed little from 1962 to 1963. Of the 1963 travel, 37.6 percent was on main rural roads comprising 14 percent of the Nation's total of 3.6 million miles of roads and streets. Some 48.0 percent of the travel was on urban streets, which comprise only 13 percent of the total mileage. Travel on local rural roads was only 14.4 percent, although these roads are 73 percent of the total mileage.

Passenger cars represented 84 percent of the vehicles registered and did 82 percent of the travel in 1963: trucks and truck combinations accounted for 16 percent of the vehicles and 18 percent of the travel; similar figures for buses were less than 1 percent.

Average vehicle performance in 1963 differ very little from that reported for 1962. T average motor vehicle traveled 9,590 miles 1963, almost half of it in cities, and consum 760 gallons of fuel at a rate of 12.42 miles p gallon. The average passenger car travel 9,378 miles and consumed 652 gallons of f at a rate of 14.37 miles per gallon. In 19 the average truck traveled a little more a the average commercial bus less than in 19 but their average rates of fuel consumpti did not change appreciably.

The travel and related information for 19 and revised information for 1962 are sho

**Table 1.—Estimated motor-vehicle travel in the United States and related data, calendar year 1963 and revised 1962 [1]**

| Vehicle type | Motor-vehicle travel | | | | | Number of vehicles registered | Average travel per vehicle | Motor-fuel consumption | | Average travel pe gallon of fuel consume |
|---|---|---|---|---|---|---|---|---|---|---|
| | Main rural road travel | Local rural road travel | Total rural travel | Urban travel | Total travel | | | Total | Average per vehicle | |
| CALENDAR YEAR 1963 | | | | | | | | | | |
| | *Million vehicle-miles* | *Million vehicle-miles* | *Million vehicle-miles* | *Million vehicle-miles* | *Million vehicle-miles* | *Thousands* | *Miles* | *Million gallons* | *Gallons* | *Miles/gallon* |
| Passenger cars [2] | 234, 641 | 90, 368 | 325, 009 | 329, 690 | 654, 699 | 69, 813 | 9, 378 | 45, 545 | 652 | 14. 37 |
| Buses: | | | | | | | | | | |
| Commercial | 877 | 170 | 1, 047 | 1, 794 | 2, 841 | [3] 82. 2 | 34, 562 | 606 | 7, 372 | 4. 69 |
| School and nonrevenue | 642 | 708 | 1, 350 | 292 | 1, 642 | 215. 7 | 7, 612 | 232 | 1, 076 | 7. 08 |
| ALL BUSES | 1, 519 | 878 | 2, 397 | 2, 086 | 4, 483 | 297. 9 | 15, 049 | 838 | 2, 813 | 5. 35 |
| All passenger vehicles | 236, 160 | 91, 246 | 327, 406 | 331, 776 | 659, 182 | 70, 111 | 9, 402 | 46, 383 | 662 | 14. 21 |
| Trucks and combinations | 64, 794 | 24, 270 | 89, 064 | 52, 809 | 141, 873 | 13, 423 | 10, 569 | 18, 133 | 1, 351 | 7. 82 |
| ALL MOTOR VEHICLES | 300, 954 | 115, 516 | 416, 470 | 384, 585 | 801, 055 | 83, 534 | 9, 590 | 64, 516 | 760 | 12. 42 |
| CALENDAR YEAR 1962 REVISED | | | | | | | | | | |
| Passenger cars [4] | 224, 699 | 87, 573 | 312, 272 | 316, 825 | 629, 097 | 66, 638 | 9, 441 | 43, 771 | 657 | 14. 37 |
| Buses: | | | | | | | | | | |
| Commercial | 863 | 167 | 1, 030 | 1, 826 | 2, 856 | [3] 78. 3 | 36, 475 | 610 | 7, 791 | 4. 68 |
| School and nonrevenue | 630 | 694 | 1, 324 | 286 | 1, 610 | 209. 7 | 7, 678 | 227 | 1, 082 | 7. 09 |
| ALL BUSES | 1, 493 | 861 | 2, 354 | 2, 112 | 4, 466 | 288. 0 | 15, 507 | 837 | 2, 906 | 5. 34 |
| All passenger vehicles | 226, 192 | 88, 434 | 314, 626 | 318, 937 | 633, 563 | 66, 926 | 9, 467 | 44, 608 | 667 | 14. 20 |
| Trucks and combinations | 61, 130 | 23, 007 | 84, 137 | 49, 152 | 133, 289 | 12, 809 | 10, 406 | 17, 089 | 1, 334 | 7. 80 |
| ALL MOTOR VEHICLES | 287, 322 | 111, 441 | 398, 763 | 368, 089 | 766, 852 | 79, 735 | 9, 618 | 61, 697 | 774 | 12. 43 |

[1] For the 50 States and District of Columbia.

[2] Includes taxicabs; also 786,318 motorcycles, which are estimated to account for 0.3 percent of the total travel.

[3] Adjusted to reflect revised procedures for eliminating duplicate motorbus registrati

[4] Includes taxicabs; also 660,400 motorcycles, which are estimated to account for 0.3 per of the total travel.

# Table 2.—Vehicle-miles of travel in 1962 on all roads and streets, free and toll, by State and highway system, estimated by State highway departments in 1964

(Millions)

| DIVISION | STATE | FEDERAL-AID HIGHWAY SYSTEM | | | | | | | | | | | | | | | | NOT ON FEDERAL-AID SYSTEMS | | | | SUB-TOTAL RURAL | SUB-TOTAL URBAN AND MUNICIPAL | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | INTERSTATE RURAL | | | INTERSTATE URBAN | | | SUB-TOTAL INTER-STATE | OTHER FAP RURAL | OTHER FAP URBAN | FAS STATE RURAL | FAS STATE URBAN | FAS LOCAL RURAL | FAS LOCAL URBAN | TOTAL FEDERAL-AID RURAL | TOTAL FEDERAL-AID URBAN | TOTAL FEDERAL-AID | OTHER STATE RURAL | OTHER STATE MUNICIPAL | LOCAL RURAL | LOCAL MUNICIPAL | | | |
| | | FINAL | TRAVELED | TOTAL RURAL | FINAL | TRAVELED | TOTAL URBAN | | | | | | | | | | | | | | | | | |
| NEW ENGLAND | Connecticut | 515 | 85 | 600 | 1,145 | 180 | 1,325 | 1,925 | 1,255 | 880 | 950 | 475 | 30 | 65 | 2,835 | 2,745 | 5,580 | 1,215 | 1,025 | 750 | 2,530 | 4,800 | 6,300 | 11,100 |
| | Maine | 223 | 331 | 554 | 42 | 57 | 99 | 653 | 1,121 | 339 | 723 | 92 | - | - | 2,398 | 530 | 2,928 | 662 | 212 | 376 | 156 | 3,436 | 898 | 4,334 |
| | Massachusetts | 713 | 316 | 1,029 | 458 | 598 | 1,056 | 2,085 | 2,539 | 2,823 | 600 | 405 | 1,131 | 1,104 | 5,299 | 5,388 | 10,687 | 108 | 93 | 3,054 | 5,227 | 8,461 | 10,708 | 19,169 |
| | New Hampshire | 152 | 104 | 256 | 20 | 53 | 73 | 329 | 903 | 283 | 595 | 74 | 4 | 4 | 1,758 | 434 | 2,192 | 212 | 50 | 250 | 383 | 2,220 | 867 | 3,087 |
| | Rhode Island | 35 | 70 | 105 | 71 | 212 | 283 | 388 | 430 | 680 | 150 | 136 | 20 | 155 | 705 | 1,254 | 1,959 | 70 | 88 | 23 | 1,102 | 798 | 2,444 | 3,242 |
| | Vermont | 49 | 257 | 306 | 4 | 62 | 66 | 372 | 579 | 95 | 221 | 7 | 102 | 20 | 1,208 | 188 | 1,396 | 4 | 5 | 181 | 189 | 1,393 | 382 | 1,775 |
| | TOTAL | 1,687 | 1,163 | 2,850 | 1,740 | 1,162 | 2,902 | 5,752 | 6,827 | 5,100 | 3,239 | 1,189 | 1,287 | 1,348 | 14,203 | 10,539 | 24,742 | 2,271 | 1,473 | 4,634 | 9,587 | 21,108 | 21,599 | 42,707 |
| MIDDLE ATLANTIC | New Jersey | 99 | 698 | 797 | 880 | 1,464 | 2,344 | 3,141 | 2,527 | 4,008 | 45 | 48 | 1,355 | 1,258 | 4,724 | 7,658 | 12,382 | 1,302 | 1,092 | 5,684 | 7,850 | 11,710 | 16,600 | 28,310 |
| | New York | 1,864 | 521 | 2,385 | 3,153 | 915 | 4,068 | 6,453 | 8,437 | 8,286 | 1,749 | 630 | 2,818 | 1,359 | 15,389 | 14,343 | 29,732 | 232 | 59 | 6,484 | 13,887 | 22,105 | 28,289 | 50,394 |
| | Pennsylvania | 2,060 | 1,271 | 3,331 | 1,375 | 1,394 | 2,769 | 6,100 | 8,458 | 5,331 | 6,133 | 3,246 | 27 | 63 | 17,949 | 11,409 | 29,358 | 3,308 | 2,816 | 1,752 | 5,766 | 23,009 | 19,991 | 43,000 |
| | TOTAL | 4,023 | 2,490 | 6,513 | 5,408 | 3,773 | 9,181 | 15,694 | 19,422 | 17,625 | 7,927 | 3,924 | 4,200 | 2,680 | 38,062 | 33,410 | 71,472 | 4,842 | 3,967 | 13,920 | 27,503 | 56,824 | 64,880 | 121,704 |
| SOUTH ATLANTIC (NORTH) | Delaware | - | 117 | 117 | 42 | 214 | 256 | 373 | 739 | 459 | 250 | 160 | - | - | 1,106 | 875 | 1,981 | - | - | 55 | 63 | 1,161 | 938 | 2,099 |
| | Dist. of Col. | - | - | - | 37 | 220 | 257 | 257 | - | 845 | - | - | - | 469 | - | 1,571 | 1,571 | - | - | - | 866 | - | 2,437 | 2,437 |
| | Maryland | 204 | 674 | 878 | 304 | 853 | 1,157 | 2,035 | 2,339 | 1,521 | 1,289 | 657 | 375 | 298 | 4,881 | 3,633 | 8,514 | 355 | 140 | 904 | 3,236 | 6,140 | 7,009 | 13,149 |
| | Virginia | 384 | 2,333 | 2,717 | 241 | 772 | 1,013 | 3,730 | 4,483 | 1,520 | 2,275 | 302 | 978 | 120 | 10,453 | 2,955 | 13,408 | 67 | 234 | 1,952 | 2,059 | 12,472 | 5,248 | 17,720 |
| | West Virginia | 152 | 516 | 668 | 11 | 342 | 353 | 1,021 | 1,589 | 366 | 1,127 | 92 | 735 | 26 | 4,119 | 837 | 4,956 | 3 | 20 | 243 | 1,178 | 4,365 | 2,035 | 6,400 |
| | TOTAL | 740 | 3,640 | 4,380 | 635 | 2,401 | 3,036 | 7,416 | 9,150 | 4,711 | 4,941 | 1,211 | 2,088 | 913 | 20,559 | 9,871 | 30,430 | 425 | 394 | 3,154 | 7,402 | 24,138 | 17,667 | 41,805 |
| SOUTH ATLANTIC (SOUTH) | Florida | 380 | 1,597 | 1,977 | 351 | 1,117 | 1,468 | 3,445 | 4,332 | 1,635 | 3,783 | 1,177 | 603 | 129 | 10,695 | 4,409 | 15,104 | 722 | 957 | 1,282 | 5,795 | 12,699 | 11,161 | 23,860 |
| | Georgia | 284 | 1,423 | 1,707 | 325 | 667 | 992 | 2,699 | 4,626 | 1,195 | 2,159 | 395 | 1,035 | 264 | 9,527 | 2,846 | 12,373 | 164 | 307 | 1,585 | 3,457 | 11,276 | 6,610 | 17,886 |
| | North Carolina | 624 | 989 | 1,613 | 121 | 158 | 279 | 1,892 | 3,462 | 1,051 | 4,434 | 505 | 3,322 | 663 | 12,831 | 2,498 | 15,329 | 52 | 113 | 865 | 2,417 | 13,748 | 5,028 | 18,776 |
| | South Carolina | 402 | 723 | 1,125 | 5 | 226 | 231 | 1,356 | 3,037 | 887 | 2,897 | 281 | 88 | 3 | 7,147 | 1,402 | 8,549 | 222 | 610 | 361 | 140 | 7,730 | 2,152 | 9,882 |
| | TOTAL | 1,690 | 4,732 | 6,422 | 802 | 2,168 | 2,970 | 9,392 | 15,457 | 4,768 | 13,273 | 2,358 | 5,048 | 1,059 | 40,200 | 11,155 | 51,355 | 1,160 | 1,987 | 4,093 | 11,809 | 45,453 | 24,951 | 70,404 |
| EAST NORTH CENTRAL | Illinois | 1,029 | 1,643 | 2,672 | 2,728 | 1,108 | 3,836 | 6,508 | 7,582 | 5,573 | 900 | 353 | 1,754 | 141 | 12,908 | 9,903 | 22,811 | 1,481 | 3,256 | 2,583 | 9,629 | 16,972 | 22,788 | 39,760 |
| | Indiana | 829 | 1,517 | 2,346 | 192 | 823 | 1,015 | 3,361 | 5,040 | 2,055 | 2,601 | 328 | 1,317 | 72 | 11,304 | 3,470 | 14,774 | 73 | 16 | 828 | 6,495 | 12,205 | 9,981 | 22,186 |
| | Michigan | 2,040 | 983 | 3,023 | 851 | 1,334 | 2,185 | 5,208 | 6,190 | 3,228 | 1,043 | 175 | 5,320 | 666 | 15,576 | 6,254 | 21,830 | 14 | 43 | 3,722 | 8,889 | 19,312 | 15,186 | 34,498 |
| | Ohio | 2,048 | 1,229 | 3,277 | 752 | 2,241 | 2,993 | 6,270 | 7,169 | 4,699 | 3,735 | 894 | 1,735 | 870 | 15,916 | 9,456 | 25,372 | 165 | 647 | 4,780 | 9,119 | 20,861 | 19,222 | 40,083 |
| | Wisconsin | 532 | 472 | 1,004 | 48 | 249 | 297 | 1,301 | 4,741 | 1,487 | 1,450 | 300 | 1,315 | 730 | 8,510 | 2,814 | 11,324 | 6 | 52 | 1,003 | 4,480 | 9,519 | 7,346 | 16,865 |
| | TOTAL | 6,478 | 5,844 | 12,322 | 4,571 | 5,755 | 10,326 | 22,648 | 30,722 | 17,042 | 9,729 | 2,050 | 11,441 | 2,479 | 64,214 | 31,897 | 96,111 | 1,739 | 4,014 | 12,916 | 38,612 | 78,869 | 74,523 | 153,392 |
| WEST NORTH CENTRAL | Iowa | 260 | 486 | 746 | 55 | 144 | 199 | 945 | 4,863 | 1,122 | - | - | 1,386 | 48 | 6,995 | 1,369 | 8,364 | 50 | 28 | 823 | 2,422 | 7,868 | 3,819 | 11,687 |
| | Kansas | 408 | 334 | 742 | 172 | 164 | 336 | 1,078 | 3,471 | 935 | 524 | 16 | 1,164 | 255 | 5,901 | 1,542 | 7,443 | 28 | 29 | 645 | 3,195 | 6,574 | 4,766 | 11,340 |
| | Minnesota | 66 | 778 | 844 | 186 | 817 | 1,003 | 1,847 | 4,250 | 1,806 | 897 | 26 | 2,179 | 125 | 8,170 | 2,960 | 11,130 | 4 | 117 | 1,036 | 2,933 | 9,210 | 6,010 | 15,220 |
| | Missouri | 530 | 1,422 | 1,952 | 586 | 647 | 1,233 | 3,185 | 4,270 | 1,491 | 1,776 | 333 | 29 | 36 | 8,027 | 3,093 | 11,120 | 89 | 446 | 1,852 | 5,669 | 9,968 | 9.208 | 19,176 |
| | Nebraska | 134 | 489 | 623 | 23 | 70 | 93 | 716 | 2,282 | 433 | 469 | 22 | 571 | 37 | 3,945 | 585 | 4,530 | - | - | 952 | 1,688 | 4,897 | 2,273 | 7,170 |
| | North Dakota | 132 | 272 | 404 | 4 | 52 | 56 | 460 | 1,121 | 78 | 164 | 2 | 429 | 13 | 2,118 | 149 | 2,267 | - | - | 607 | 353 | 2,725 | 502 | 3,227 |
| | South Dakota | 140 | 384 | 524 | 7 | 10 | 17 | 541 | 1,432 | 178 | 158 | 21 | 390 | 19 | 2,504 | 235 | 2,739 | 10 | 10 | 565 | 307 | 3,079 | 552 | 3,631 |
| | TOTAL | 1,670 | 4,165 | 5,835 | 1,033 | 1,904 | 2,937 | 8,772 | 21,689 | 6,043 | 3,988 | 420 | 6,148 | 533 | 37,660 | 9,933 | 47,593 | 181 | 630 | 6,480 | 16,567 | 44,321 | 27,130 | 71,451 |
| EAST SOUTH CENTRAL | Alabama | 206 | 1,099 | 1,305 | 17 | 493 | 510 | 1,815 | 3,140 | 1,239 | 1,013 | 207 | 1,673 | 174 | 7,131 | 2,130 | 9,261 | 34 | 43 | 420 | 2,619 | 7,585 | 4,792 | 12,377 |
| | Kentucky | 260 | 862 | 1,122 | 112 | 514 | 626 | 1,748 | 3,125 | 674 | 2,614 | 209 | 444 | 88 | 7,305 | 1,597 | 8,902 | 453 | 414 | 902 | 1,560 | 8,660 | 3,571 | 12,231 |
| | Mississippi | 138 | 680 | 818 | 54 | 370 | 424 | 1,242 | 2,870 | 527 | 640 | 64 | 744 | 105 | 5,072 | 1,120 | 6,192 | 5 | 21 | 520 | 955 | 5,597 | 2,096 | 7,693 |
| | Tennessee | 97 | 1,713 | 1,810 | 202 | 626 | 828 | 2,638 | 3,651 | 1,199 | 966 | 577 | 547 | 54 | 6,974 | 2,658 | 9,632 | 31 | 3 | 1,545 | 2,963 | 8,550 | 5,624 | 14,174 |
| | TOTAL | 701 | 4,354 | 5,055 | 385 | 2,003 | 2,388 | 7,443 | 12,786 | 3,639 | 5,233 | 1,057 | 3,408 | 421 | 26,482 | 7,505 | 33,987 | 523 | 481 | 3,387 | 8,097 | 30,392 | 16,083 | 46,475 |
| WEST SOUTH CENTRAL | Arkansas | 105 | 746 | 851 | 21 | 277 | 298 | 1,149 | 2,302 | 485 | 1,661 | 250 | 296 | 31 | 5,110 | 1,064 | 6,174 | 17 | 57 | 772 | 870 | 5,899 | 1,991 | 7,890 |
| | Louisiana | 109 | 1,117 | 1,226 | 57 | 688 | 745 | 1,971 | 1,918 | 821 | 2,620 | 390 | 3 | - | 5,767 | 1,956 | 7,723 | 481 | 256 | 320 | 994 | 6,568 | 3,206 | 9,774 |
| | Oklahoma | 716 | 540 | 1,256 | 220 | 542 | 762 | 2,018 | 5,052 | 1,171 | 1,179 | 246 | 629 | 157 | 8,116 | 2,336 | 10,452 | 85 | 180 | 949 | 515 | 9,150 | 3,031 | 12,181 |
| | Texas | 835 | 2,682 | 3,517 | 2,219 | 2,322 | 4,541 | 8,058 | 8,298 | 5,022 | 5,710 | 1,897 | - | - | 17,525 | 11,460 | 28,985 | 1,143 | 462 | 2,254 | 11,743 | 20,922 | 23,665 | 44,587 |
| | TOTAL | 1,765 | 5,085 | 6,850 | 2,517 | 3,829 | 6,346 | 13,196 | 17,570 | 7,499 | 11,170 | 2,783 | 928 | 188 | 36,518 | 16,816 | 53,334 | 1,726 | 955 | 4,295 | 14,122 | 42,539 | 31,893 | 74,432 |
| MOUNTAIN | Arizona | 395 | 1,396 | 1,791 | 91 | 322 | 413 | 2,204 | 850 | 111 | 595 | 88 | 537 | 1,220 | 3,773 | 1,832 | 5,605 | 128 | 19 | 667 | 966 | 4,568 | 2,817 | 7,385 |
| | Colorado | 344 | 786 | 1,130 | 127 | 483 | 610 | 1,740 | 1,882 | 903 | 820 | 105 | - | - | 3,832 | 1,618 | 5,450 | 31 | 38 | 1,093 | 1,909 | 4,956 | 3,565 | 8,521 |
| | Idaho | 162 | 523 | 685 | 10 | 78 | 88 | 773 | 1,254 | 119 | 358 | 16 | 249 | 21 | 2,546 | 244 | 2,790 | 2 | 4 | 555 | 485 | 3,103 | 733 | 3,836 |
| | Montana | 112 | 588 | 700 | 1 | 89 | 90 | 790 | 1,204 | 164 | 332 | 28 | - | - | 2,236 | 282 | 2,518 | - | - | 712 | 444 | 2,948 | 726 | 3,674 |
| | Nevada | 168 | 480 | 648 | - | 84 | 84 | 732 | 560 | 144 | 192 | 23 | 96 | 30 | 1,496 | 281 | 1,777 | 27 | 26 | 93 | 153 | 1,616 | 460 | 2,076 |
| | New Mexico | 325 | 865 | 1,190 | 21 | 236 | 257 | 1,447 | 1,319 | 387 | 700 | 111 | 6 | 1 | 3,215 | 756 | 3,971 | 96 | 315 | 316 | 582 | 3,627 | 1,653 | 5,280 |
| | Utah | 98 | 889 | 987 | 6 | 488 | 494 | 1,481 | 680 | 261 | 560 | 219 | 159 | 28 | 2,386 | 1,002 | 3,388 | 24 | 121 | 337 | 523 | 2,747 | 1,646 | 4,393 |
| | Wyoming | 140 | 561 | 701 | 9 | 59 | 68 | 769 | 730 | 55 | 213 | 1 | 16 | 12 | 1,660 | 136 | 1,796 | 2 | 3 | 246 | 352 | 1,908 | 491 | 2,399 |
| | TOTAL | 1,744 | 6,088 | 7,832 | 265 | 1,839 | 2,104 | 9,936 | 8,479 | 2,144 | 3,770 | 591 | 1,063 | 1,312 | 21,144 | 6,151 | 27,295 | 310 | 526 | 4,019 | 5,414 | 25,473 | 12,091 | 37,564 |
| PACIFIC | California | 549 | 5,040 | 5,589 | 4,235 | 4,762 | 8,997 | 14,586 | 8,014 | 9,602 | 1,884 | 910 | 3,648 | 3,078 | 19,135 | 22,587 | 41,722 | 495 | 1,209 | 12,035 | 25,828 | 31,665 | 49,624 | 81,289 |
| | Oregon | 709 | 559 | 1,268 | 232 | 120 | 352 | 1,620 | 2,022 | 806 | 932 | 123 | 732 | 105 | 4,954 | 1,386 | 6,340 | 57 | 29 | 1,044 | 1,483 | 6,055 | 2,898 | 8,953 |
| | Washington | 310 | 1,447 | 1,757 | 221 | 971 | 1,192 | 2,949 | 2,356 | 630 | 1,248 | 185 | 1,227 | 250 | 6,588 | 2,257 | 8,845 | 54 | 98 | 2,584 | 2,224 | 9,226 | 4,579 | 13,805 |
| | TOTAL | 1,568 | 7,046 | 8,614 | 4,688 | 5,853 | 10,541 | 19,155 | 12,392 | 11,038 | 4,064 | 1,218 | 5,607 | 3,433 | 30,677 | 26,230 | 56,907 | 606 | 1,336 | 15,663 | 29,535 | 46,946 | 57,101 | 104,047 |
| TOTAL - ALL DIVISIONS | | 22,066 | 44,607 | 66,673 | 22,044 | 30,687 | 52,731 | 119,404 | 154,494 | 79,609 | 67,334 | 16,801 | 41,218 | 14,366 | 329,719 | 163,507 | 493,226 | 13,783 | 15,763 | 72,561 | 168,648 | 416,063 | 347,918 | 763,981 |
| | Alaska 1/ | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Hawaii | - | 225 | 225 | - | 149 | 149 | 374 | 457 | 122 | 186 | 11 | - | - | 868 | 282 | 1,150 | - | - | 317 | 607 | 1,185 | 889 | 2,074 |
| UNITED STATES TOTAL | | 22,066 | 44,832 | 66,898 | 22,044 | 30,836 | 52,880 | 119,778 | 154,951 | 79,731 | 67,520 | 16,812 | 41,218 | 14,366 | 330,587 | 163,789 | 494,376 | 13,783 | 15,763 | 72,878 | 169,255 | 417,248 | 348,807 | 766,055 |

1/ Alaska has no interstate mileage and therefore did not prepare an estimate. Total 1962 vehicle-miles in Alaska are estimated to be 797 million.

in table 1 by road system and vehicle type. Such data have been reported in PUBLIC ROADS magazine for a number of years; the latest for 1962 appeared in volume 32, No. 11, December 1963, p. 268.

Each State highway department prepared 1962 travel estimates on a uniform basis as a foundation for Traffic forecasts needed for the report to The Congress, *1965 Estimate of the Cost of Completing the National System of Interstate and Defense Highways.* These estimates, on a uniform basis, were prepared in accordance with instructions issued by the Bureau of Public Roads. Detailed State-by-State travel estimates by highway system are shown in table 2.

According to the State estimates, the traveled way of the Interstate System carried 119.8 billion vehicle-miles, or 15.6 percent of the total 1962 travel on all roads and streets. The traveled way consisted of 11,000 miles of Interstate System highways now in use and 30,000 miles of existing connecting highways; service for this total mileage will be provided by the completed Interstate System. From the State estimates it is expected that by 1975 the 41,000-mile Interstate System, comprising little more than 1 percent of the total road and street mileage of the United States, will carry 285 billion vehicle-miles, or nearly 25 percent, of the total 1,165 billion miles of travel estimated for 1975. Earlier estimates had indicated that the Interstate System would be carrying more than 20 percent of all traffic in 1971.

According to the State estimates of 1962 travel, all Federal-aid systems combined, which includes about 24 percent of all roads and streets, carried 65 percent of all travel. Because of their principal use in a report to The Congress, the State estimates of 1962 travel were made according to a system classification and rural-urban distinction directly related to the Federal-aid program. In the Federal-aid law, an urban area is "an area including and adjacent to a municipality or other urban place having a population f 5,000 or more . . . ." In the annual es- mates reported in table 1, however, urb signifies the areas within the political boun- aries of municipalities such as cities, boroug, and villages. As a consequence, urban trav in 1962 as shown in table 1 was 48.0 perce of the total, but by the State estimates t was 45.5 percent.

In recent years the annual travel estima reported in table 1 have been developed part from trend indicators, extending from base of comprehensive studies by the Stat of travel in 1957. The State estimates f travel in 1962 have now provided a new ba, and from this base the revised estimates f 1962, also shown in table 1, were prepar The revised estimate of total travel in 19 is only 0.1 percent less than the origi estimate. One of the largest differences w in the proportion of urban travel, which w revised from 46 percent of total travel to percent.

# Films Available from the Bureau of Public Roads

In addition to the two most recent films—*Sand Drains* and *Spur Dikes*—described erein under *New Publications and Films*, the ollowing described films produced by the Bureau of Public Roads are available to Government agencies, State and local highway departments, engineering colleges and niversities, and other responsible organizaions interested in highway development and nprovement. No charge is made for the se of these films but the borrower must pay ransportation charges both ways. Requests or films should be submitted well in advance f the desired showing and alternate dates for howing should be given. The films must be eturned promptly. Correspondence concernng these films should be addressed to: Photoraphic Section, Bureau of Public Roads, Washington, D.C., 20235.

*THE PENNSYLVANIA PILOT STUDY:* 6-mm. color sound—25 minutes (1949). A echnical movie filmed on the Pennsylvania Turnpike and parallel route to illustrate the erformance of heavy motor vehicles as afected by varying conditions of load, road, nd grade. The tests were conducted by the Bureau of Public Roads in cooperation with he Committee on Economics of Motor Vehiles Size and Weight of the Highway Research Board and other allied organizations.

*HIGHWAY SOIL ENGINEERING:* 16-mm. color sound—1 hour 50 minutes (1950). A technical film illustrating the methods emloyed for surveying and sampling in the eld and testing in the laboratory the subrade soils encountered in highway construcion. The tests are those practiced by the Bureau of Public Roads and many State highay departments in accordance with standards dopted by the American Association of State Highway Officials.

*INTER-AMERICAN HIGHWAY REPORT—PART I, MEXICO:* 16-mm. color ound—55 minutes (1951). The film illusrates the present conditions of the InterAmerican Highway in Mexico and shows what the traveler may expect with respect to cenery, highway conditions, and accommoations. Animated maps portray the location f the highway south from the Americanborer at Laredo, Tex., to the junction with the nter-American Highway in Guatemala.

*INTER-AMERICAN HIGHWAY REPORT—PART II, CENTRAL AMERICA:* 6-mm. color sound—62 minutes (1952). The lm illustrates the present conditions of the outherly 1,600 miles of the Inter-American Highway extending from the Mexico-Guatemala boundary through the Central America Republics of Guatemala, El Salvador, Honduras, Nicaragua, and Costa Rica, and hence through Panama to Panama City. Animated maps show the location of the highway in each country and define the passable sections.

*ROAD TEST ONE, MD.:* 16-mm. color sound—78 minutes (1953). This film depicts the operation of and explains the conclusions drawn from the test conducted in 1950 at La Plata, Md., under the direction of the Highway Research Board in behalf of 11 Eastern States and with the cooperation of the Bureau of Public Roads, to study the effects of controlled truck traffic of different loadings on a concrete pavement. The nature and causes of pumping, cracking, and stresses are demonstrated by means of working models.

*PRECAST CONCRETE BRIDGE:* 16-mm. color sound—18 minutes (1955). The film illustrates, with scenes at an actual bridge site and with animated drawings, a method of bridge building that is growing in usage in this country. The nature of the forms for the precast concrete beams, deck slabs, and curb sections, and their use in the central casting yard, are demonstrated in detail. Driving of piles and construction of bent caps, placement of the precast units, and the final operations involved in completing the three-span structure are shown step by step.

*LOST PRODUCTION IN HIGHWAY CONSTRUCTION:* 16-mm. color sound—30 minutes (1957). The film examines minor delays that affect production rates of key units of highway construction equipment including power shovels, scrapers, hot-mix bituminous plants, and concrete paver. Contrasts in operation practices shown in the motion picture are very revealing.

*POWER SHOVEL PRODUCTIVITY:* 16-mm. color sound—30 minutes (1958). The film, based on extensive studies conducted by Public Roads highlights the job conditions that determine the yardage output of power shovels on highway grading work and demonstrates how production is affected by the speed of dipper cycle, size of dipper load, and frequency and duration of minor delays.

*LOST MIXING TIME ON DUAL-DRUM PAVER:* 16-mm. color sound—30 minutes (1959). The film highlights the importance of the simultaneous mixing interval in meeting mixing time specifications with dual-drum pavers. It shows some trouble spots and the significance of proper adjustments to the batchmeter.

*DUAL-DRUM PAVER PRODUCTIVITY:* 16-mm. color sound—30 minutes (1960). Action scenes from actual paver operations illustrate how and to what extent operating delays affect paver productivity on the jobs where paver production rates ranged from low on some to outstanding on others. The film shows the extent to which the number of batch trucks required to supply the paver is affected by batch plant efficiency and capacity as well as haul road variables. The simultaneous showing of contrasting action scenes effectively highlights fast versus mediocre batch truck dumping performance at the skip.

*INTRODUCTION TO HIGHWAY HYDRAULICS:* 16-mm. color sound—21 minutes (1960). This film illustrates some fundamental principles of hydraulics of open channel flow. The principles are illustrated by hydraulic models in the laboratory and correlated with field highway installations where possible. The film was produced in cooperation with Colorado State University.

*WINTER DRIVING:* 16-mm. color sound—24 minutes (1960). Produced in cooperation with the National Safety Council, it illustrates safe winter driving techniques for starting, stopping, and cornering on snow- and ice-covered roads, and includes a demonstration of a relatively easy method of installing tire chains. It presents tips on how to avoid skids and shows how to recover from a skid if it does occur. Suggestions on preparing your car for winter driving are also included. This film is especially appropriate for driver education classes, off-the-job safety programs, and civic gatherings and is available to Federal agencies and State highway departments through Bureau of Public Roads. For others, it is available either on a rental basis or by purchase from the National Safety Council, 425 North Michigan Avenue, Chicago, Ill., 60611.

*WINTER DRIVING (TV):* 16-mm. black and white sound—15 minutes (1962). A shortened version of the film *Winter Driving* produced in cooperation with the National Safety Council and released in 1960. The TV version covers the same information, using the same photography reproduced in black and white. For TV use especially.

*SAFETY IN HIGHWAY SURVEYING:* 16-mm. color sound—25 minutes (1960). The functions of a highway survey party are shown with the hazards and appropriate precautions for working in rough country, dense vegetation, timberland and mountainous country as well as along the highway. Different hand tools and equipment such as axes, machetes, chain saws, and lifelines are demonstrated together with an explanation of hazards and safe working practices. Survey work and inspections performed in cooperation with actual construction are also included with emphasis on the hazards peculiar to this phase. Precautions taken for the safety and convenience of the traveling public during survey and construction are shown.

*RIGHT-OF-WAY FOR HIGHWAYS:* 16-mm. color sound—26 minutes (1961). Shows how a State highway department studies, evaluates, and selects the route for a new highway; the various steps in the appraisal of a property needed for right-of-way; and the negotiation for purchase of the property. The participation of Public Roads in Federal-aid projects is also shown. The film was produced in cooperation with the States of Iowa, Minnesota, Missouri, and Nebraska. Can be used for orientation of new highway personnel, for introductory training in right-of-way work, at public hearings, and for public information generally.

*THE WASHO ROAD TEST:* 16-mm, color sound—35 minutes (1956). This film depicts the operation and major findings of the large-scale road test undertaken cooperatively by the Western Association of State Highway Officials, the Bureau of Public Roads, and motor vehicle and petroleum industries, under the direction of the Highway Research Board. The road near Malad, Idaho, was especially built to determine the effect of controlled heavy traffic on bituminous pavement.

*LAREDO TO PANAMA—THE INTER-AMERICAN HIGHWAY:* 16-mm, color sound—18 minutes (1964). The story of the economic and social benefits brought to the people of Mexico and Central America by the Inter-American Highway. Shows the industrial, agricultural, and educational growth developing in these countries and how the highway has been instrumental in improving communications and the exchange of cultures in these ancient lands.

*HIGHWAY BRIDGE RESEARCH:* 16-mm, color sound—18½ minutes (1964). Shows methods used in conducting strain research on steel and reinforced concrete bridges. Details installation of gages, wiring, and instrumentation; shows operation; explains equipment; and gives results.

*THE ROAD TO PROSPERITY:* 16-mm, color sound—13½ minutes (1964). Explains the economic impact on America of the Interstate Highway System through on-the-spot statements by four Kansas businessmen and scenes taken over the country.

*TARGET: URBAN MOBILITY:* 16-mm, color, sound—18 minutes (1965). After describing the rapid population growth taking place in the United States, the film explains the meaning of section 9 of the Federal-Aid Highway Act of 1962 concerning requirements for an urban transportation planning process in urban areas having a population greater than 50,000. It then briefly outlines the 10 basic technical elements for which inventories and analyses are necessary in organizing and carrying out the cooperative, comprehensive, and continuing urban transportation planning process.

*HURRICANE HITS THE HIGHWAYS:* 16-mm, color sound—13½ minutes (1962). Photography during and after the 1961 hurricane Carla, that struck the Texas gulf coast area, shows the power of the storm and the damage to buildings, highways, and bridges. The film tells the story of the havoc brought by the winds and water, and the role played by Public Roads in cooperation with the Texas Highway Department and other government agencies in rebuilding and repairing roads and bridges so that normal activity could be restored.

*AASHO ROAD TEST: CONSTRUCTION AND MATERIALS:* 16-mm, color sound—27 minutes (1962). This film follows the history of the construction and illustrates the methods of preparing the test roads for the $27 million AASHO Road Test. It covers the construction aspects from the clearing of the test site in 1956 to completion of the test loops in 1958. It records the quality and control features that were built into each tangent of rigid and flexible pavement and explains the objectives of the research program, "to relate the performance of the pavement and bridges directly to design and loading."

*AASHO ROAD TEST: PAVEMENT RESEARCH.* 16-mm, color sound 37 minutes (1962). This film covers the objectives, methods, and principal results of the pavement research conducted in the AASHO Road Test. It shows how the pavement loops were tested under specific loads, at known speeds, how the roads stood up to the tests, and the methods used to measure serviceability. The results of the test program are presented dramatically and graphically.

*AASHO ROAD TEST: THE ROAD TO BETTER ROADS.* 16-mm, color sound—14 minutes (1963). This film explains, in lay terms, the kind of research done in the area of highway construction, as shown by the AASHO Road Test. The picture begins by establishing the need for such projects and the variety of programs involved. The main story is of the construction and operation of the AASHO tests and the accumulation and processing of data.

*SKID CORRELATION STUDY:* 16-mm, color sound—14 minutes (1963). Compares various techniques used in testing the coefficients of friction on five specially constructed pavements at Tappahannock, Va. Study was for the purpose of standardizing techniques and equipment used by highway departments and research organizations.

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# PUBLICATIONS
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nnual Reports of the Bureau of Public Roads:

1960, 35 cents. 1963, 35 cents. 1964, 35 cents. (Other years are now out of print.)

### EPORTS TO CONGRESS

ederal Role in Highway Safety, House Document No. 93 (1959). 60 cents.

ighway Cost Allocation Study:

Final Report, Parts I–V, House Document No. 54 (1961). 70 cents.

aximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems, House Document No. 354 (1964). 45 cents.

### UBLICATIONS

Quarter Century of Financing Municipal Highways, 1937–61. $1.00.

ccidents on Main Rural Highways—Related to Speed, Driver, and Vehicle (1964). 35 cents.

ggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and A New Graphical Evaluation Chart (1962). 25 cents.

merica's Lifelines—Federal Aid for Highways (1962). 15 cents.

librating and Testing a Gravity Model With a Small Computer (1964). $2.50.

assification of Motor Vehicles, 1956–57 (1960). 75 cents.

esign Charts for Open-Channel Flow (1961). 70 cents.

ederal Laws, Regulations, and Other Material Relating to Highways (1960). $1.00.

nancing of Highways by Counties and Local Rural Governments: 1942–51 (1955). 75 cents.

ighway Bond Financing . . . An Analysis, 1950–1962. 35 cents.

ighway Finance 1921–1962 (a statistical review by the Office of Planning, Highway Statistics Division). 15 cents.

ighway Planning Map Manual. $1.00.

ighway Planning Technical Reports—Creating, Organizing, and Reporting Highway Needs Studies (1964). 15 cents.

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Highway Research and Development Studies Using Federal-Aid Research and Planning Funds (1964), $1.00.

Highway Statistics (published annually since 1945):

1956, $1.00. 1957, $1.25. 1958, $1.00. 1959, $1.00. 1960, $1.25. 1961, $1.00. 1962, $1.00. 1963, $1.00.

Highway Statistics, Summary to 1955. $1.00.

Highway Transportation Criteria in Zoning Law *and* Police Power and Planning Controls for Arterial Streets (1960). 35 cents.

Highways and Social and Economic Changes (1964). $1.25.

Hydraulics of Bridge Waterways (1960). 40 cents.

Increasing the Traffic-Carrying Capability of Urban Arterial Streets: The Wisconsin Avenue Study (1962). 40 cents. Appendix, 70 cents.

Interstate System Route Log and Finder List. 10 cents.

Landslide Investigations (1961). 30 cents.

Manual for Highway Severance Damage Studies (1961). $1.00.

Manual on Uniform Traffic Control Devices for Streets and Highways (1961). $2.00.

Part V—Traffic Controls for Highway Construction and Maintenance Operations (1963). 25 cents.

Opportunities for Young Engineers in the Bureau of Public Roads (1964). 15 cents.

Peak Rates of Runoff From Small Watersheds (1961). 30 cents.

Reinforced Concrete Pipe Culverts—Criteria for Structural Design and Installation (1963). 30 cents.

Road-User and Property Taxes on Selected Motor Vehicles, 1964. 45 cents.

Selected Bibliography on Highway Finance (1951). 60 cents.

Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1958: a reference guide outline. 75 cents.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-61 (1961). $2.25.

Standard Plans for Highway Bridges (1962):

Vol. I—Concrete Superstructures. $1.00.
Vol. II—Structural Steel Superstructures. $1.00.
Vol. III—Timber Bridges. $1.00.
Vol. IV—Typical Continuous Bridges. $1.00.

The Identification of Rock Types (revised edition, 1960). 20 cents.

The Role of Aerial Surveys in Highway Engineering (1960). 40 cents.

Traffic Assignment Manual. $1.50.

Traffic Safety Services, Directory of National Organizations (1963). 15 cents.

Transition Curves for Highways (1940). $1.75.

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